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LECTURES

ON

NATURAL AND EXPERIMENTAL PHILOSOPHY,

CONSIDERED IN IT'S PRESENT STATE OF

IMPROVEMENT.

DESCRIBING, IN A FAMILIAR AND EASY MANNER,

THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING,

THAT THEY ALL CO-OPERATE IN DISPLAYING

THE

GOODNESS, WISDOM, AND POWER OF GOD.

BY GEORGE ADAMS,

Mathematical Inſtrument Maker to His Majeſty, and Optician to His Royal
Highneſs the Prince of Wales.

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LECTURES ON NATURAL PHILOSOPHY.

OF THE NATURE AND PROPERTIES OF WATER.

LECTURE XII.

THE ſtudy of nature is as much diſtinguiſhed from other ſubjects by the importance of it's matter, as by the variety of it's topics. But amidſt all this variety, the *true philoſopher* is intereſted by the objects, *only* in proportion to the indication they afford of deſign and providence in the government of the world. This conſoling teſtimony you will find ſpread abundantly over the face of nature; it is every where diſtributed into maſſes and portions, according to the nature of the ſubject. Every object we meet with, great or ſmall, bears the ſtamp of an ALL PERFECT CREATOR, is a mark of his wiſdom, a monument of his power, and a proof of his goodneſs: many inſtances of the order, beauty, harmony, and proportion, in the works of nature, have been exhibited in the foregoing Lectures. The ſubjects that I am going to treat of in this Lecture will furniſh us with more.

As you advance in the knowledge of nature's varieties, your mind will be opened, and you will find freſh ornament in truth, freſh dignity in devotion, and freſh reaſon in religion. By thus employing your contemplations, you will not only enjoy the pureſt pleaſure, but you will learn in the ſcriptural phraſe to *walk with God*, and cheriſh towards him a certain loyalty of heart that brings all the ardours and ſenſibilities of our nature to the ſide of religion.*

From treating of air and fire, I now proceed to conſider the nature of *water*, whoſe wonderful properties are alone an abundant ſource of knowledge. It is a ſubſtance that in a certain degree of heat is *fluid*, in a leſs it is *ſolid*, and with a greater degree is convertible into an *elaſtic vapour* of incredible force. It is capable of diſſolving all kinds of ſalts, of abſorbing and detaining in it's ſubſtance the air of the atmoſphere, of being elevated and ſuſpended in immenſe quantities in the regions thereof. In the general œconomy of nature, water promotes ſolution, ſeparation, aſſociation, and ſubſidence. It is a ſubſtance which enters into ſo many operations both of nature and art, that to give you a full deſcription of it's properties would include thoſe of moſt other ſubſtances.

It's weight is uſed as the meaſure of *ſpecific gravity*. It's *temperature* at the changes from ſolidity to fluidity, and from thence to the elaſtic ſtate, are taken for the fixed points of thermometers.

Water conſtitutes not only the principal part of blood, milk, wine, oil, and other fluids, but alſo enters in a large proportion into the conſtitution of the ſolid parts of all animal, vegetable, and of many mineral ſubſtances.

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* Looker-on, No. 12.

Water ſerves to the art and navigation of man, as air ſerves to the wings of the feathered ſpecies. It is the eaſy and ſpeedy medium, the ready conduct and conveyance, whereby all redundancies are carried off, and all wants ſupplied. It makes man as it were a denizen of every country on the globe. It ſhortens every diſtance, and ties the remoteſt regions together. It carries and communicates the knowledge, the virtues, the manufactures and arts of each clime to all. It gives ſprings to induſtry, energy to invention.

OF THE COMPOSITION AND DECOMPOSITION OF WATER.*

Until very lately this fluid has been always conſidered as a ſimple ſubſtance. The experiments of Mr. Lavoiſier, which I have related to you in a former Lecture, has induced many to conſider it as a compound, conſiſting of inflammable and vital airs: in other words, that the whole maſs of any quantity of water may be converted into inflammable and vital air: and that the combuſtion of theſe airs produces a volume of water proportioned to the weight of the airs employed in the experiment. Though I have already ſhewn you, that the experiments of Mr. Lavoiſier and the French chemiſts by no means warrant the deductions they have made from them, yet as they have made theſe experiments the baſis of a new ſyſtem of chemiſtry, and have invented and appropriated a new ſet of terms, in order to propagate it more readily, it will be neceſſary in this place further to inveſtigate the ſubject.

That

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* Dr. Prieſtley's Obſervations and Experiments on Air. Keir's Chemical Dictionary.

That their experiments do not authorize their concluſion, appears from this, that when vital and inflammable airs are decompoſed by heat, we find both from the experiments of Dr. Prieſtley and the French chemiſts, that the *nitrous acid* is always formed; and though this acid has been ſaid to come from the phlogiſticated air, which could not be wholly excluded in the proceſs, there are ſeveral conſiderations that prove the acid could not have this ſource; the more ſo, as this proceſs does not at all decompoſe, or in the ſmalleſt degree affect phlogiſticated air.

In what ever manner, ſays Dr. Prieſtley, vital and inflammable air be made to unite, *ſome acid* is produced, and in no caſe *pure water*. If iron, containing phlogiſton, be heated in vital air; or if precipitate per ſe, containing vital air, be heated in inflammable air, fixed air is always formed; whereas, according to the modern hypotheſis, water ought only to be produced in both caſes.

Water, they aſſert, is always decompoſed when it is made to paſs over red-hot iron; the iron according to their opinion imbibing the acidifying principle, the remainder going off in inflammable air. Now it is unfortunate for this hypotheſis, that no ſubſtances will anſwer for this experiment, except ſuch as have always been conſidered as containing phlogiſton. It is therefore moſt probable to ſuppoſe, that the inflammable air is formed by the phlogiſton from theſe ſubſtances, *water* being the baſe; and that if any part of the ſubſtance remain and acquire weight, it receives that additional weight from water only.

That phlogiſton is an element of water ſeems probable, 1ſt, becauſe water conducts electricity like metals and charcoal, into which the ſame principle enters; and 2dly, becauſe when freſh diſtilled it attracts vital air from the atmoſphere, which is alſo a property of other bodies containing phlogiſton. In this ſenſe it may be ſaid to contain both the principles of the new theory, though it is a ſenſe that entirely overthrows that theory.

Without however entering more minutely into this inveſtigation, it is ſufficient to obſerve, that the formation of nitrous acid from the combuſtion of inflammable and vital airs, clearly proves *that water is not a compound of theſe airs; or that it is only ſo, in a certain proportion of theſe ingredients, while another proportion yields nitrous acid.*

For by admitting the formation of the nitrous acid from the ſame fluids, the argument for the compoſition of water drawn from the complete ſubſtitution of an equal weight of water to that of the airs which diſappear by combuſtion, no longer exiſts; and as the appearance of a large quantity of water in theſe experiments is readily explained from the precipitation of the water which is known to be ſuſpended in theſe elaſtic fluids, or which even make a neceſſary part of their compoſition, no fact remains on which the hypotheſis of the formation of water from any proportion of inflammable and vital air is grounded. The *fundamental* experiment of this doctrine, namely, the equal ſubſtitution of water, and nothing but water, to the airs which diſappear, being removed, the *ſtructure* with all it's ornaments muſt fall, and no other veſtige will remain but the ingenuity and ſkill of the artiſt.

OF WATER IN A FLUID STATE.

Water is conſidered as a pellucid, colourleſs fluid, taſteleſs, and without ſmell, nearly incompreſſible, and elaſtic only in a ſmall degree. It adheres to the ſubſtance of moſt bodies, but penetrates and incorporates with a ſtill greater number. It extinguiſhes flame. It is capable of paſſing through various ſtates of aggregation, from the ſolidity of ice to the tenuity of vapour.

Many have conſidered *ice* as the natural ſtate of water, and the fluidity thereof as a ſtate of violence, or as ice kept in continual fuſion, and returning to it's former ſtate, when deprived of a certain quantity of fire. Were you to define lead and water, you would call one a ſolid, the other a fluid, eſteeming theſe their natural condition. Yet if water be not acted upon and combined with a certain quantity of fire, it becomes a ſolid. We call that *ſtate* natural which falls immediately under our obſervation. If we had lived in *Saturn*, we ſhould have given but one name to ice and water, although we might now and then have ſeen it liquified in ſummer; and on the other hand, had we been born in *Mercury*, we ſhould have deemed lead a fluid.

The particles of water, though moveable amongſt themſelves with the greateſt eaſe, yet adhere together with a certain force; thus a drop of water remains ſuſpended at the end of the finger, although the inferior particles only touch other particles of the ſame fluid. This adherence of the particles prevents ſmall needles, or very thin plates of metal from ſinking therein, as they reſiſt diviſion more than the exceſs of the ſpecific gravity of theſe bodies over a relative volume of water.

Water can only be compreſſed in a very ſmall degree, ſo ſmall that it may in general be conſidered as incompreſſible, as will be evident to you by conſidering the Florentine experiment which I have already mentioned to you. That it is, however, compreſſible in a ſmall degree, may be proved by an eaſy experiment: put water into a bottle with a ſtem nicely graduated, obſerve the degree at which it ſtands, and place the bottle under the receiver of an air-pump, and exhauſt the air therefrom; when the preſſure of the air is removed, the fluid will riſe a little.

We have no fluid more ſubtil and penetrating than water, except fire; it enters into the minuteſt particles and pores of matter, the fineſt veſſels of animals, and the ſmalleſt tubes of plants, and will pierce through ſubſtances which will detain air itſelf. This penetrative power of water, together with it's ſmoothneſs and lubricity, renders it a fit *vehicle* for the eaſy conveyance of the nutritious matter of all bodies.

It enters into the compoſition of all the ſubſtances belonging to our earth. There is probably no ſubſtance, whether animal, vegetable, or mineral, without it. Every being with life, in a great degree lives by it; and whatever grows, through it receives it's growth; and wherever it enters, according to the œconomy of providence, it promotes and ſuſtains life, preſerving all material nature in their proper claſſes of exiſtence. It bears a part in the formation and decompoſition of all the mineral kingdom. It is neceſſary to the free exerciſe of the functions of the animal body, and haſtens and facilitates the deſtruction of both vegetables and animals as ſoon as they are deprived of life. But whether you conſider it as productive of health to animals and vegetables, as requiſite to the beauty and exiſtence of the earth, or as one of the great powers by which GOD works in the ſuſtentation and action of the whole univerſe; you cannot but admire the ſublime propriety with which, as a ſenſible image, it is uſed in the ſacred ſcriptures, to repreſent divine truth, and the holy influence of our GOD and SAVIOUR.

PRESENCE OF WATER IN THE ATMOSPHERE.

So great is the neceſſity, uſe, and importance of this fluid in all things, that ſome ancient philoſophers were impreſſed with a notion of it's being the firſt principle of univerſal life. It ſeems to be univerſally diffuſed. And it will be eaſy to convince you of the great quantity contained in the air. You may be ſaid to walk in an ocean; the water indeed of this ocean does not become the object of our ſenſes, we cannot ſee it, nor, whilſt it continues thus ſuſtained in the air, do we feel that it wets us; but it is ſtill water, though it is neither viſible nor tangible; juſt as ſugar, when diſſolved in water, is ſtill ſugar, though we can neither ſee it, nor feel it. Some are puzzled to find water enough to form an univerſal deluge; * to aſſiſt their endeavours it may be remarked, that were the whole precipitated which is contained in the air, it might probably be ſufficient to cover the ſurface of the whole earth to the depth of above 30 feet. If a bottle of wine be fetched out of a cool cellar in the hotteſt and drieſt day of ſummer, it's ſurface will ſoon be covered with a thick vapour, which when taſted appears to be water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for the glaſs is impervious to water, and the bottle remains full, and when wiped dry it is found to weigh as much as when taken out of the cellar. The ſame appearance is obſervable on the outſide of a ſilver, or any other metallic veſſel, in which iced water is put in the ſummer time; and it is certain, that the water which is condenſed on the ſurface of the veſſel does not proceed merely from the moiſture exhaled by the breathing of the people in the room, where you may notice the experiment, becauſe the ſame effect will take place if the veſſel be put in the open air. Water which is cooled by the ſolution of any ſalt, or even ſpring-water which happens to be a few degrees colder than the air, produces a ſimilar condenſation of vapour

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* Watſon's Chemiſtry, vol. iii. p. 87.

vapour on the outſide of the veſſel in which it is contained. Theſe, and other appearances of the ſame kind are to be explained on the ſame principle. When warm air becomes contiguous to the outward ſurface of a veſſel containing cold liquor, the fire by which the water is ſuſpended in the air, and quits and paſſes through the veſſel into the liquor, to reſtore it to the temperature of the place, and the water ceaſing to be ſuſpended in the air, attaches itſelf to the ſurface of the cold veſſel.

Another method of proving the exiſtence of water in the cleareſt air, is, to obſerve the increaſe of *weight*, which certain bodies acquire by expoſure to the open air. Dr. Watſon put into the open air eight ounces of ſalt of tartar, which had been well dried on a hot iron; the day was without a cloud, the barometer at 30 inches; in the ſpace of three hours, from 11 to 2 in the afternoon, the ſalt had increaſed two ounces in weight. In the courſe of a few days it's weight was increaſed to 20 ounces; it was then quite fluid, and being diſtilled, it yielded a pure water, equal in weight nearly to the increaſe it had acquired from the air. Strong acid of vitriol is another body, which abſorbs humidity ſtrongly from the air. An ounce of this acid has been obſerved to gain in twelve months above ſix times it's own weight.

The increaſe of weight experienced by the human body (in many caſes from the water, which the pores of the body ſuck in from the air) is another very ſenſible proof of the great quantity of water ſuſpended in the air. The Biſhop of Llandaff mentions, among many inſtances, one of a lad, at Newmarket, a few years ago, who having been almoſt ſtarved, in order that he might be reduced to a proper weight for riding a match, was weighed at nine o'clock in the morning, and again at ten, and was found to have gained near thirty ounces in weight in the courſe of an hour, though he had drank only half a glaſs of wine in the interval. The wine, probably, ſtimulated the action of the nervous ſyſtem, and incited nature, exhauſted by abſtinence, to open the abſorbent pores of the whole body, in order to ſuck in ſome nouriſhment from the air. It is well known, that perſons, who go into a warm bath, come out ſeveral ounces heavier than they went in, their bodies having imbibed a correſpondent quantity of water. Part of the utility of medicated vapour-baths depends on this principle of imbibition by the pores.

There is a circumſtance of importance concerning the human frame, which ſeems to have eſcaped the attention of moſt phyſiologiſts, namely, the nature of animal moiſture; and the means by which it is ſupported and kept up. I have ſhewn you, in this Lecture, what a quantity of moiſture the human frame will take from the air; and this might have been ſupported by a greater variety of facts, if there had been any further neceſſity for proof. There are ſeveral conſiderations independent of theſe facts, which will of themſelves lead you to conclude, that animal moiſture cannot be altogether ſupported, or accounted for, by what is received internally, as meat and drink; and you will be led to think that the greater part is received from the atmoſphere; and that it is probable that the human frame has a power of decompoſing ſome of the aerial fluids, which abound in the atmoſphere, and procuring water from them.

The conſiderations alluded to above, are, that the fluids conſtitute more than half the bulk and matter of the animal frame; that the baſis of theſe fluids is water; that they have a ſtrong vaporific tendency, and are continually heated to 96 degrees; that a vaſt ſurface is expoſed to the drying power of the air, not only the whole external ſurface, but that alſo of the lungs; and that every vital fibre and particle is not only expoſed to this heat, but alſo to the motion ariſing from the rapid circulation of the ſyſtem.

If to all theſe circumſtances, we take in the great heat to which the body is expoſed in warm climates, I think we may, with little heſitation, ſay, that if the ſame quantity of water, that is contained in the human frame, were expoſed to as large a ſurface of air, more than one half would be evaporated in 24 hours; for you are to conſider that moiſture can tranſpire through our ſkin; and that the ſkin is always moiſt, and is continually acted upon by animal heat, the air, and the general circulation; and that without a continued and ſucceſſive ſupply of moiſture, the ſkin would be quite parched up.

Add to this, the immenſe diſcharges which are conſtantly iſſuing out of the human ſyſtem, by inſenſible perſpiration, by the great diſcharges from the lungs, by the natural evacuations, by urine, ſaliva, &c. Take theſe altogether, and I think it will be impoſſible for you to conceive theſe are all ſupplied by the mouth.

Mr. Harrington ſays, that he has often, in winter, examined his evacuation by urine, and found it to exceed in quantity, the moiſture received into the ſyſtem by the mouth. Whence then could the ſuperabundant quantity ariſe? and what ſupported the other evacuations? what under a heat of 96° kept every minute part moiſt, ſoft, and pliable? Many more facts might be adduced in ſupport of this opinion; but for them I muſt refer you to your own obſervation, and Mr. Harrington's work.

OF WATER AS MIXED AND COMBINED WITH BODIES.

You may conſider the water, that is in bodies, in two ſtates, either that of ſimple *mixture*, or that of *combination.*

In the firſt ſtate, it renders bodies humid, is perceptible to the eye, and may be diſengaged from them with facility.

In the ſecond ſtate, it exhibits no character whereby you can diſcover that it is thus combined. It exiſts in this form, in cryſtals, ſalts, plants, animals, &c.

Water, exiſting in a ſtate of combination, concurs in imparting to them hardneſs; and the tranſparent ſalts, and moſt ſtony cryſtals loſe their tranſparency, when they are deprived of the water of cryſtallization. Many bodies are indebted to water for their fixity; the acids, for example, only acquire fixity by combining with water. Water, when mixed with earth or aſhes, is formed into a veſſel, which when baked will bear the utmoſt force of the hotteſt fire that art can contrive. Thus you ſee a body, whoſe fluid and diſſolving qualities are ſo obvious, giving conſiſtence and hardneſs to all the ſubſtances of the earth. In this ſtate nature often unites it to bodies, with which art has not yet learned to make it enter into combination.

Pure water will, indeed, unite immediately only with a certain number of ſubſtances; but after being united with theſe, it becomes capable of diſſolving other ſubſtances in a ſucceſſion, whoſe limits we cannot determine, becauſe the further we advance in the knowledge of ſubſtances, the greater reaſon we have for perceiving our ignorance of the number which exiſt diſtinctly, and of the intimate ingredients even of thoſe that are

known.

known. *Water* is the baſe of all menſtrua: we concentrate them to a certain point by evaporation; but beyond this point the liquid either produces nothing but vapour, or eſcapes entirely. An eſſential part of the art of *chemiſtry* conſiſts in the compoſition of *menſtrua*, and in the precipitations operated therein: in theſe proceſſes water itſelf often enters into new combinations. If, in his operations, the chemiſt falls upon any lucrative proceſs, of which he himſelf is ignorant of the intimate cauſes, he makes a *ſecret* of it. But how many ſuch ſecrets are to be found among the operations of nature? How many that will be concealed from us for ever, becauſe the primitive ſubſtances are arrived at a ſtate that cannot be changed by the agents of the preſent operations in nature.

When water, by a ſucceſſion of diſſolutions, contains different ſubſtances, they may be ſucceſſively precipitated, in two ways, by the diſſolution of new ſubſtances, or by the emiſſion of expanſible fluids, ſome of whoſe ingredients were united with the ſubſtances in the liquid. Ancient chemiſts knew ſcarce any thing of this laſt proceſs, nor of the various combinations of fire and light. It is to modern diſcoveries on theſe heads, that we are indebted for the preſent advancement of theſe ſciences; but if the chemiſt, in theſe purſuits, neglects the ſtudy of meteorology and geology, both for directing his inveſtigations of the nature of expanſible fluids, and appreciating his deciſions on the intrinſic nature of ſubſtances, he will run the riſk of accrediting errors by the very facts which ſhould have ſeparated him from them.*

Water may be conſidered as a kind of general cement. The ſtones and ſalts, which are deprived of it, become pulverulent, and fall away into a maſs of ſhapeleſs duſt. Water facilitates the coagulation, re-union, and conſiſtence of the particles of ſtones, of ſalts, &c. as you alſo ſee in the operations performed with plaſters, lutes, mortar, &c.

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* See De Luc's Letters, dans le Journal de Phyſique, for 1790-91-92, &c.

The ſtock of water afforded by the drieſt bodies is ſurpriſing; hartſhorn kept forty years, and thereby become as hard and dry as any metal, ſo that if ſtruck againſt a flint, it would give ſparks of fire; upon being diſtilled, afforded one eighth part of it's quantity of water.

For a conſiderable time water was thought to be a fluid earth. The earthy reſidue, left after the diſtillation, trituration, and putrifaction of water, gave credit to the opinion that it was convertible into earth. Mr. Lavoiſier has ſhewn, that this earth ariſes from the wear of the veſſels; and Scheele has proved the identity in the nature of the earth with that of the veſſels in which the operations were made.

In a fluid ſtate water combines ſo eaſily with other ſubſtances, that it is never to be found in a pure ſtate; the moſt genuine is mixed with exhalations, and diſſolutions of various kinds. Rain-water, which is a fluid of nature's own diſtilling, and which has been raiſed ſo high by evaporation, is nevertheleſs a very mixed ſubſtance, impregnated with exhalations of all kinds; ſalts, ſulphurs, and metals, are combined with it. Mr. Chaptal, from experiments made at Montpellier, found rain-water in ſtormy weather more impure than that which came in gentle ſhowers; the water which falls firſt, is leſs pure than that which falls after ſeveral hours or ſeveral days rain: that the water which fell when the wind blew from the ſea to the ſouthward, contained ſea-ſalt, while that which was produced by a northerly wind did not contain a ſingle particle. The water caught pouring from the tops of houſes is impregnated with the ſmoak of the chimnies, the vapours of the ſlates and tiles, and with ſuch impurities as birds and animals have depoſited there. It is the ſame with river-water; plants, minerals, and animals, all contribute their ſhare to add to it's impurities; wherever the ſtream flows, it receives a tincture from it's channel. Of the various river-waters, thoſe of the Indies and the Thames are ſaid to be the lighteſt and moſt wholeſome.

Waters in general are ſuppoſed to be more pure as they are more ſoft; ſnow-water is very ſoft; rain-water comes next to it; ſpring-water, though the cleareſt and moſt tempting of all to look at, is the leaſt pure, and of all others the leaſt fit for common uſe. Spring-water is pure, or polluted, in proportion as the earth through which it ſtreams is more or leſs impregnated with ſulphur, ſalts, arſenic, minerals, &c. Thoſe that are ſtrained through a ſandy ſoil, free from ſaline or metallic ſubſtances, are the pureſt. The eye is no adequate judge on this occaſion. It will indeed teach you not to drink or uſe foul or dirty water, but it will leave you in the dark as to thoſe contents of the water which may be ſuſpended in it imperceptibly. Tranſparency is certainly a very agreeable quality in water, but cannot be relied on as a proof of ſalubrity, for ſea-water is as tranſparent as that which is freſh. The water of ſtagnate lakes and pools is in general very impure, and may be conſidered as a jelly of floating inſects, the whole teeming with ſhapeleſs life, growing more fruitful by increaſing putrifaction, forming a maſs of corruption, diſpleaſing to the ſenſe and injurious to the health.

The atmoſphere itſelf may be looked upon not only as the general receptacle of all aqueous vapours, but likewiſe of all mineral exhalations of the ſteams which are conſtantly ariſing from the perſpiration of whatever enjoys animal or vegetable life, and from the inſtantaneous putreſcence of thoſe ſubſtances, when deprived of life; of the ſmaller ſeeds of terreſtrial and aquatic plants, of the eggs of an infinite ſpecies of imperceptible animalcules, of the acids and oils ſeparated by combuſtion from all ſorts of fuel, of the matter of light, of electric effluvia, and a variety of other ſubſtances. From theſe ſources are derived many of the impurities which have been diſcovered in all atmoſpherical water, which muſt vary according to the nature of the ſubſtances, the climate, the ſeaſon of the year, the direction of the winds, and many other unknown cauſes.

After all, we muſt be contented with but an impure mixture for our beverage, and yet even this may often be more ſerviceable to our healths than thoſe deemed purer. Experience alone muſt determine it's uſeful and noxious qualities; ſuch water is in general to be preferred that ſits light upon the ſtomach, that is of a freſh, lively, agreeable taſte, that boils readily, and boils garden ſtuff, and particularly peas and pulſe quickeſt, and which mixes perfectly and readily with ſoap without curdling.

Water is purified by diſtillation. As it is of importance on many occaſions to have very pure water, it will be neceſſary to point out to you the means by which it may be thus purified. The operation is performed in a veſſel called an alembic; the alembic conſiſts of two pieces, a boiler or cucurbit, and a covering called a capital or head.

The water is put into the cucurbit, from which it is raiſed in vapour by means of fire, and theſe vapours are condenſed by cooling the head with cold water. The vapours thus condenſed flow into a veſſel deſigned to receive them. This is called diſtilled water; and is purified ſo far as it leaves behind it in the cucurbit the ſalts and other fixed principles which alter it's purity. The diſtillation is more ſpeedy and quick in proportion as the preſſure of the air is leſs upon the ſurface of the ſtagnant fluid.

A true diſtillation is carried on every where at the ſurface of our globe. The heat of the ſun raiſes water in the form of vapours, theſe remain a certain time in the atmoſphere, and afterwards fall in the form of dew by ſimple refrigeration. This riſe and fall of water waſhes and purges the atmoſphere of all thoſe particles, which by their corruption or developement might render it infectious. It is perhaps this combination of water with various miaſmata, which renders the evening dew unwholeſome.

OF THE ORIGIN OF SPRINGS AND RIVERS.

The quantity of water raiſed in vapour from the ocean, has rather extravagantly been thought by ſome to be equal to that which is poured into the ocean by all the rivers upon earth; and they therefore ſuppoſe, that what the ſea gets by the rivers, it loſes by evaporation, and that thus a mutual and equable interchange is preſerved; that all the rivers are ſupplied with water by the vapours that are raiſed from the ſea, carried thence by the wind, condenſed againſt the ſides of mountains, where trickling down through the crannies of the rocks, they enter the hollow places thereof, and form collections of water, from whence they iſſue out at the firſt orifice they can find, and by this means conſtitute ſprings and rivers.

There is another theory to account for ſprings and rivers, which refers this cauſe to a great abyſs of waters, occupying the central parts of our globe. It aſſerts, that all the phenomena of ſprings are chiefly derived from the vapours, veins, and iſſues of this great abyſs, into which they are all returned; and that a perpetual circulation and equality is kept up, the ſprings never failing, and the ſea by reaſon of it's communication with the ſubterranean waters never overflowing.

From the earlieſt ages theſe phenomena have engaged the attention of every inquiſitive mind. "The ſun ariſeth," ſays Solomon, "and the ſun goeth down, and pants for the place from whence he aroſe. All things are filled with labour, and man cannot utter it. All rivers run into the ſea, yet the ſea is not full. Unto the place whence the rivers come, thither they return again. The eye is not ſatisfied with ſeeing, nor the ear with hearing." At ſo early a period was curioſity employed in obſerving theſe great circulations of nature. The inquiry whence rivers are produced, whence they derive thoſe unceaſing flows of water, which are continually enriching the world with fertility and verdure, has been variouſly conſidered, and divided the opinions of mankind.* But as the two abovementioned theories are thoſe which generally prevail, and to which moſt others may be reduced, we ſhall only examine their merits.

"It ſeems almoſt unkind to diſenchant the beauties of the proſpect, which the firſt of the two foregoing theories preſents to our minds. A romantic imagination can form nothing more ſtriking than this unceaſing rotation of waters; clouds ariſing from the ocean, travelling till they daſh againſt the tops of the higheſt mountains, then deſcending feebly in little ſtreams down their ſides, entering the ſubterranean caverns of the earth, burſting forth into ſprings, and at laſt aſſembling into rivers, which carry the united torrent again to it's parent ocean." This is amuſing ſpeculation, but alas! it is but ſpeculation, and is ſo preſſed with difficulties, that a more perfect theory is highly deſirable.

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* Goldſmith's Hiſt. of the Earth, vol. i. p. 134.

Calculation has been preſſed to favour this ſyſtem, and ſo great a quantity of evaporated water contrived to ſupport it, that if it fell, would drown inſtead of refreſhing our earth.

That the rain and vapour which fall upon the earth are inadequate to the ſolution of the phenomena, and cannot poſſibly account for the origin of ſprings and rivers, will be made evident to you from a variety of conſiderations. Monſ. Gualtieri, by comparing the rivers of a country with the rains that fall upon it, has ſhewn that after making more allowances than are reaſonable in favour of the evaporating hypotheſis, they exceed the rain in quantity: he has alſo ſhewn, that it is utterly impoſſible for the rain-water to keep up the continual courſe of rivers and ſprings. The waters diſcharged by the rivers of Italy into the ſea, are to the rain which falls upon the land, as 55 to 27, that is, more than twice the quantity.

The earth is conſtantly moiſtened to a greater depth than the rain of the year will account for. Mr. De la Hire brought this hypotheſis to the teſt of experiment, by examining the moſt eſſential article thereof, namely, the depth that rain and ſnow-water did really deſcend into the earth. To know this, he dug a hole in the lower terrace of the obſervatory at Paris, and placed therein, eight feet under ground, a large leaden baſon, a little inclined towards one of it's angles, to which was ſoldered a pipe 12 feet long, which, after a conſiderable deſcent, reached into an adjoining cellar. After having covered the head of the pipe with ſeveral flints of different ſizes, to prevent the orifice from being ſtopped, he threw in a quantity of earth to the depth of eight feet; the earth was of a nature between ſand and loam, and thus eaſily permeable by water. He judged, that if rain or ſnow-water penetrated the earth to the depth that ſome ſprings are found at, (which in digging wells and mines are diſcovered to be at all depths from 8 to 800 feet,) or till they meet with the firſt clayey or compact ſtratum to ſtop them; that if this were the caſe there would ſoon be a ſpring burſting forth through the leaden pipe into the cellar. But on the contrary, after having kept the baſon in this ſituation for no leſs than *fifteen years*, and the ground all the while expoſed *openly* to all the rains, ſnow, or vapours that might fall, yet he could not obſerve that a ſingle drop of water had ever paſſed through the leaden pipe into the cellar.

At the ſame time that Mr. De la Hire commenced the above deſcribed experiment, he placed another baſon about eight inches under ground, and choſe a place where the rain and vapours might fall, and yet the ground be ſcreened from the heat of the ſun and the action of the wind; taking care to pull up the graſs and herbs that grew over the baſon, that all the water which ſhould fall on the ground might paſs uninterrupted to the bottom of the baſon, wherein there was a little hole with a tube to convey the water to another veſſel. In eight months, that is, from the 12th of June to the 19th of February following, *no* water came by the tube, and though it *began to run* on the 19th of February, this was entirely owing to the great quantity of ſnow which had fallen, and was then melting. From that time the earth in the baſon was always very moiſt, though the water would only run a few hours after raining, and it ceaſed running when the quantity falling was drained off.

A year after he repeated the ſame experiment, but buried the baſon *ſixteen inches* under ground, taking care that there was no graſs on the ground, and that it might be ſcreened from the ſun and wind; the effect was much the ſame as before, excepting that when a conſiderable time paſſed without raining, the earth would grow a little dry, ſo that a moderate rain coming on it would *not* moiſten it ſufficiently to make it run.

The conſumption of moiſture by vegetables, and the fruits, is much greater than has been commonly ſuppoſed, or generally allowed for; ſo great, that all the rain that falls is not ſufficient to ſupply them with the quantity equal to what their growth demands. Mr. de la Hire planted herbs on the ground over the baſon mentioned in the laſt experiment, and found that when theſe were grown up a little, the ground was ſo far from ſending any water after rain, that *all that fell was not ſufficient to ſuſtain them*, but that they would droop and wither unleſs reſprinkled from time to time with water. Dr. Hales found, that a plant in 21½ days drew off all the water of the earth on which it grew, ſo that without a farther ſupply from beneath it would periſh after that period; and yet he has made no allowance for what the earth in queſtion perſpired at the ſame time in vapour. Theſe conſiderations, which might be ſupported by many more, abundantly prove, not only that rain-water ſcarcely penetrates ſo far as two feet, but that the quantity which falls is not ſufficient to furniſh what is requiſite for the growth of vegetables; ſo that we muſt call in ſome foreign aſſiſtance for their ſupport.

There are ſprings, and thoſe common every where, ſo equal and conſtant in yielding their water at all ſeaſons, and which are neither affected by rains nor droughts, that we cannot ſuppoſe them to be dependent on theſe for cauſes. The Reverend

Mr. Derham * deſcribes one ſuch under his own inſpection, which was by no means conſiſtent with the hypotheſis of rain and vapour.

There are ſprings alſo too near the ſummits of the higheſt grounds in the country to derive themſelves by deſcent from the water which falls on the ſurface of the ground, there being no declivity adequate to the purpoſe.

The evaporation from the ſea being condenſed by high mountains, and ſoaked in there, is by no means ſufficient for the production of ſprings and rivers; † for whatever effect this vapour may ſeem to have in ſouthern climates, and in iſlands placed in the middle of the ocean, it cannot fairly be applied to the ſprings of inland countries and northern climates. Nor have the advocates for this hypotheſis conſidered, that where the evaporation of the day is ſo copious, the dews of the night which fall again on the ſame ſurface (ſea or land) are nearly in the ſame proportion; ſo that much leſs has been gained in this way than has been generally ſuppoſed. Dr. Derham ſhews alſo, that ſprings occur in great plenty, and are conſtant in their courſe, even in times of the greateſt drought, where the country is in general very low, and there are no mountain tops to condenſe the vapours.

The vapours and rain fall alſo upon the ſea as well as upon the land; and the ſurface of the ocean is conſidered to be as large again as that of the dry land: ſo that we may juſtly ſuppoſe, that two thirds of whatever is raiſed in vapours returns from whence it came without falling upon the dry land.

No one will deny that rain and melted ſnow will produce many temporary ſprings, and increaſe the

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* Philoſ. Tranſ. No. 289, and 313.

† Memoirs of Literature, Aug. 1725. Jones's Phyſiological Diſquiſitions, p. 490. Catcott on the Deluge, p. 174.

the diſcharge of rivers; but this is a partial conſideration, and by no means adequate to that conſtant ſupply, and to that vaſt quantity of waters which are to be accounted for, and which are conſtantly in action.

I ſhall, therefore, now conſider the ſubterraneous ſtore,* and the vapours that ariſe from them. And here it is a well known fact, that we never fail to find water when we penetrate deep enough into the bowels of the earth; and the deeper we go, the waters occur in greater plenty. This does not look as if their ſtores depended upon any accident at the ſurface, for then they would rather be diminiſhed and fail us when we work lower, their ſupplies being extended according to this account in ſprings and rivers upon the ſurface: but the contrary is always the caſe; therefore the ſources are not above, but below. This concluſion ſeems too obvious to be avoided. In ſinking mines it is very common to break in upon veins, and ſometimes large and powerful courſes of water in incredible quantities, which either overflow the works, or require continual aſſiſtance to drain them.

When the earth is cut through, it yields water, as naturally as the body, which abounds with veſſels, yields blood when it is wounded. The deeper the wound the greater is the effuſion of blood, becauſe the largeſt channels lie deep, and the largeſt of all which feed the reſt, are placed in the central parts of the body. Thus it is with the body of the earth, the effuſions of water obſervable near the ſurface have their ſupply from reſervoirs which lie deeper, and they in their turns are fed by larger and deeper, till we come to the grand repoſitory

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* Thoſe who wiſh to ſee ſtrong evidence in favour of theſe ſubterraneous ſtores, ſhould conſult Calcott on the Deluge, and Jones's Diſquiſitions, p. 525.

of all, which keeps up a general communication between the waters of the land and thoſe of the ſea.

Thoſe who have been eye-witneſſes of what paſſes within the earth, have been generally of opinion, that ſteam and vapour is in continual action there, though more at ſome times than at others; that there is frequently a very ſenſible warmth at the greateſt depths, and many tokens of moiſture ariſing upwards from the lower parts. Scheuchzer, who was very converſant in theſe reſearches, ſays, "firmiter perſuaſus ſum, copioſiſſimus ex imis montis viſceribus ad cacumen ſublevari caloris ſubterranei ope vapores aqueos." Now as the waters of the ſea are ſalt, while the ſpring waters of the land are freſh, and conſequently lighter, a column of ſea water will be a counterpoiſe to an higher column of freſh water. If therefore the waters of deep ſeas have any communication with the land, and their weight has due effect, water may riſe to any required height upon ſtatical principles, either by running channels, or by ſap and percolation; for water underneath a maſs of dry ſand will be ſoaked upwards to it's ſurface.* Sir Iſaac Newton tried this experiment on a tube filled with dry aſhes, and found the water aſcend through them with eaſe. In the rocky caverns of mountains much may be effected by the ſlow aſcent of ſteam, which will be condenſed as it comes near to the air, and diſtil downwards through thoſe cracks and chaſms where it finds an outlet.

When we dig for ſprings in ſmall iſlands, and lands lying near the ſea coaſts, it is common to find veins of brackiſh water; theſe are certainly derived from the ſea. The water that is more remote,

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* Since this work went to the preſs, a machine has been publiſhed for purifying water by aſcent. The contrivance is Mr. Peacock's.

mote, and at a greater elevation from the ſea, becomes freſh by degrees; therefore it ſweetens in it's progreſs by percolation. Here the proceſs is palpable. But the earth being full of open veins and fiſſures, and ſtrata of looſe and permeable matter, muſt have a communication with the ſea to great diſtances; and where the diſtance is ſo great that the lateral ſupply cannot take place, thoſe deeper communications, of which there are ſo many evidences, will never fail us; and where percolation cannot reach, the ſubterraneous vapours, which are always circulating, muſt have their effect.

In ſhort, wherever you dig beneath the ſurface of the earth, except in very few inſtances, water is to be found, and it is probable that by this ſubterraneous water ſprings and rivers, nay a great part of vegetation itſelf, are ſupported. It is this ſubterraneous water raiſed into ſteam by the internal heat of the earth that feeds plants. It is this ſubterraneous water that diſtills through it's interſtices, and there cooling, forms fountains. It is this that by the addition of rains is increaſed into rivers, and pours plenty over the whole earth.

This reaſoning may be illuſtrated by a pleaſing apparatus, which is ſold in our ſtreets by the itinerant Italians. The tube is about three feet high, and is fixed to a board, the tube near the top is globular, and will hold a large quantity of water, from whence it is continued of a leſs ſize to the bottom, where it is curved upwards, and annexed to another globe, from whence proceeds upwards another ſmaller tube, bent in an irregular meandering manner to the top, where it is curved as you ſee downwards, and is joined to the upper globe. In the inſide of the lower globe, one part of the tube is ſo contracted as to form a fit paſſage for a ſpring, or jet d'eau, to ariſe from it. I pour coloured water into the tube by means of this aperture,

ture, letting it riſe therein till it has filled the upper globe; the air in the lower globe will be condenſed by the preſſure of the water endeavouring to riſe to it's level, the reaction and ſpring of the air will impel the water you ſee upwards through the ſmall tube and all it's meanders, and make it fall into the upper globe, and thus cauſe a conſtant circulation as long as any water remains in the upper globe. Now if you ſuppoſe the upper globe to repreſent the ſea, the lower globe to repreſent the abyſs, and the jet d'eau to be a ſpring breaking out therefrom into the hollow parts of the earth, and from thence continued through ſmall winding fiſſures to the ſurface, and from the channels of the river into the ſea again, the one may be allowed to be a proper repreſentation of the other, and an experimental illuſtration of the poſſibility of ſuch a circulation.

OF THE SALTNESS OF THE SEA.

No ſooner have we endeavoured to diſcuſs one queſtion, than another preſents itſelf for our conſideration, one for which philoſophy has not yet found a ſatisfactory ſolution. To diſcover the primary cauſe of that peculiar bitteriſh ſaltneſs which characterizes ſea-water, has exerciſed the naturaliſts of all ages; and Father Kircher long ſince obſerved, that the fluctuations of the ocean were ſcarcely more various than the opinions of men concerning it's ſaline impregnation. Dr. Halley,* who often endeavoured by weak ſpeculations to leſſen the authority of the Bible, thought he had hit upon a principle, which would diſcover the cauſe of the ſaltneſs of the ſea, and carry us back almoſt with demonſtration to the true date of the creation. He laid it down as a principle, that the water of the ſea derives all it's ſaltneſs from the land, that a ſmall portion of ſalt is continually waſhed down from the land by rivers, and carried into the ſea, which has gradually acquired it's preſent quantity of ſalt from the long continued influx of rivers. The water which is thus carried into the ſea by the rivers, is again ſeparated from it by evaporation, nothing but freſh water riſes from the ſea in vapours, the ſaltneſs remains behind. The ſalt thus carried into the ſea muſt for ever remain there, it muſt therefore be a perpetually increaſing quantity, and the ſea muſt every year become more and more ſalt. If therefore, ſays the doctor, the increment of ſalt could be found for any given term of years or ages, we ſhould then be able to work backwards by the rule of proportion, and diſcover the time when the ſea firſt began to grow ſalt; that is, when the world began to exiſt. It is rather mortifying for infidelity, that the problem requires ages for it's ſolution. The idea of *ſalting* the ſea with *freſh* water, is alſo rather uncommon, but worthy of a ſceptical philoſopher. The reaſoning is defective in many points. For allowing that the ſea evaporates into freſh water, and that thus the ſalt it contains is left behind, yet we are ſtill no nearer than before, unleſs while the ſea is loſing freſh water by evaporation, you could ſtop all the rivers, ſo that no freſh water might be added in the mean time. For Dr. Halley maintained, as you ſaw before, that as much freſh water is carried to the ſea by the rivers as it loſes by evaporation, that the rivers therefore will all be running on, and bringing in freſh water, while the vapour is riſing from the ſurface; thus you ſee when things are compared together, the argument will end in a cypher.

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* Phil. Tranſ. No. 344. Watſon's Chemiſtry, vol. ii. p. 93. Jones's Diſquiſitions, p. 524.

The poſtulatum, on which the argument is built, is itſelf erroneous, as it ſuppoſes the water of the ocean was freſh at the beginning of the world; and the whole inquiry ſeems to be after the cauſe of a phenomenon which has probably no ſecondary cauſe at all.* The ſuppoſition that the water of the ocean was originally freſh, is an opinion concerning a matter of fact, which can never be proved either way; and it is ſurely extending ſpeculation too far, when we attempt to explain a phenomenon coeval with the formation of the earth. The ſaltneſs of the ſea is as neceſſary to the conſtitution of that element, and to the well-being of the terraqueous globe, as the redneſs of the blood is neceſſary to the improvement of the ſerum in the animal ſyſtem. The ſea is no more ſalt by chance, than the blood is red by chance. It is a wiſe proviſion of the CREATOR, that the immenſe body of water which occupies more than two thirds of the globe ſhould be thus ſalted and ſeaſoned for it's own preſervation, and for the ſalubrity of the atmoſphere; on which account the ocean is ſalter under the torrid zone, where the heats are more productive of putrifaction, and the ſaltneſs decreaſes as we approach the pole, all indicating deſign, and if it be true that the agitation and ventilation of the ſea is not ſufficient in vaſt tracts and deep waters to keep it ſweet without a due proportion of ſalt, Dr, Halley's ſcheme would have poiſoned the world.

The degree of ſaltneſs in the ſea varies in the ſame place at different ſeaſons, ſometimes at different depths.

Dr. Watſon informs us, that from ſome experiments made in a voyage from England to Bombay, in the Eaſt Indies, that the weight of ſea-water was the greateſt, not preciſely at the equator; but where the ſun was vertical, and where in ſimilar circumſtances the heat was greateſt; and that the weights of equal bulks of Thames-water, of ſea-water at Teneriffe, and at St. Jago, were 659, 673 $\frac{1}{2}$, 780 $\frac{1}{2}$ grains, the proportion of which number may be expreſſed thus: Thames water 1000, Teneriffe ſea-water 1022, St. Jago ſea-water 1184. In general, ſea-water poſſeſſes about $\frac{1}{32}$ or $\frac{1}{26}$ of it's weight in ſalt. He alſo mentions the following ſimple method for eſtimating the quantity of ſalt in ſea-water; a method ſo ſimple that every common ſailor may underſtand and practiſe it. Take a clean towel, or any other clean cloth, dry it well in the ſun or before a fire, then weigh it accurately, and note down it's weight, dip it in ſea-water, and when taken out wring it a little till it will not drip; weigh it in this wet ſtate, then dry it, and when it is perfectly dried, weigh it again; the exceſs of the weight of the wetted cloth above it's original weight is the weight of the ſea-water *imbibed* by the cloth; and the exceſs of the weight of the cloth after being dried above it's original weight is the weight of the ſalt retained by the cloth; and by comparing this weight with the weight of ſea-water imbibed by the cloth, you obtain the proportion of ſalt water contained in that ſpecies of ſea-water.

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* See Watſon's Chemiſtry. Jone's Phyſiological Diſquiſitions,

Congealed ſea-water will, when thawed, yield freſh water. To prove this, ſome ſea-water was taken up off the North Foreland; it was expoſed to a freezing atmoſphere, and it afforded an ice perfectly free from any taſte of ſalt. The ſpecific gravity of the water produced from the melting of the ice was ſomewhat greater than that of diſtilled rain-water, and ſomewhat leſs than a mixture of rain and ſnow-water taken out of a water-tub. The degree of cold at which the ſea-water froze was 28 $\frac{1}{2}$ of Fahrenheit's thermometer, or 3 $\frac{1}{2}$ lower than that in which common water freezes. This difference will vary according to the quantity of ſalt contained in the water. The freezing of ſea-water was formerly practiſed, and is probably ſtill ſo in the northern parts of Europe, with a view to leſſen the expence and trouble of extracting ſalt from ſea-water.

A variety of attempts have been made in our own and other countries to procure freſh from ſea-water: the means uſed for this purpoſe is diſtillation, and the moſt approved methods are thoſe of Dr. Irving, and Mr. Poiſſonier. To give you an idea of this method, ſuppoſe a tea-kettle to be made without a ſpout, and with a hole in the lid in the place of the knob; then the kettle being filled with ſea-water, the freſh vapour which ariſes from the ſea-water as it boils, will iſſue out through the hole in the lid; into that hole fit the mouth of a tobacco-pipe, letting the ſtem have a little inclination downwards; then will the vapour of freſh water take it's courſe through the ſtem of the tube, and may be collected by fitting a proper veſſel to it's end: this will give you a general though imperfect idea of an apparatus for this uſeful purpoſe.

I have already mentioned to you the diſſolving power of water, and, in one of the preceding Lectures, given you ſuch reaſons as will probably induce you to think that this power is chiefly to be attributed to it's combination with, and the preſence of fire acting in it. Salts are the ſubſtances which it diſſolves the ſooneſt, and in the greateſt quantity; it will not diſſolve equal quantities of all kinds of ſalts, ſome being more ſoluble therein than others; all ſalts are more ſpeedily diſſolved in warm than in cold water. When water is ſaturated with any kind of ſalt in a definite degree of heat, it will retain that ſalt as long as it retains it's heat; but if the heat be leſſened, the tranſparency of the ſolution will be deſtroyed, a part of the ſalt will become viſible, and fall to the bottom; what thus falls down will be re-diſſolved as ſoon as the water regains the fire it had loſt. Thus the quantity of the ſalt which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the ſolution is ſaturated, and partly on the degree of cold to which the ſolution is reduced. Thus water of 80 degrees, when ſaturated with ſalt, contains more ſalt than it would do if it had only 70 degrees of heat; and in being cooled to 50 degrees, the precipitation will be greater in the firſt inſtance than in the ſecond. Salt is much longer in being diſſolved when it is in a compact ſtate, than when it is reduced into a fine powder, becauſe when it is in the form of powder it preſents a much larger ſurface to the water than when it is one ſolid lump.

When ſalts are mixed with water, a conſiderable quantity of air is ſeparated from the water, and the whole of the fluid appears muddy, occaſioned by a number of very ſmall bubbles, which riſe to the top ſo as to form a ſcum; when all are riſen, the water again becomes tranſparent. This phenomenon ſhould be noticed, as many have been deceived by it, eſpecially thoſe who have written on mineral waters; they often ſpeak of an efferveſcence in them where there really is none, and the appearance of it is nothing more than the air eſcaping.

The more ſalt you add to water, the more ſlowly it will be diſſolved; after a certain quantity, it will diſſolve no more; the points at which the ſalts ceaſe to diſſolve is called the point of *ſaturation.* The proportion of water is very different with reſpect to different ſalts. Sir Iſaac Newton ſuppoſed, that there was an equal diſtribution of ſalt through a determined ſpace of water; hence their depoſition in regular order. The ſalt often requires ſome time before it can be ſo diſſeminated that it's particles may be arranged at equal diſtances throughout the whole fluid; in time, however, this is effected. Throw a heavy ſalt, as blue vitriol, into a glaſs of water, it at firſt ſinks to the bottom, and after ſome days begins to impart it's colour and qualities to the particles of water immediately ſurrounding it: as that part of the water which is in contact only acts on the ſalt, it is ſoon ſaturated, and being thus rendered heavier, remains round the ſalt as an atmoſphere; the reſt of the water acts on this ſurrounding atmoſphere, therefore in a little time another ſtratum will be formed containing leſs ſalt than the former; innumerable horizontal ſtrata will at length be formed containing leſs and leſs ſalt: hence the diffuſion is very ſlow, unleſs it be aſſiſted by agitation. The vitriolic acid is uſed in bleaching, being diluted in the water in which the linen is ſteeped. The bleachers at firſt thought it was enough merely to throw the acid into the water; this, however, always corroded ſome of the linen, becauſe the vitriolic acid always ſinks to the bottom, and remains there a long time before it is regularly diſſeminated. When mixed thoroughly by agitation, the ſalt will never ſeparate again.

There is another phenomenon attending the ſolution of ſalts, namely, the production of cold; this we have already explained to you, and ſhewn that it depends on the quantity of fire abſorbed to maintain and keep up the fluidity of the ſalt.

LECTURE XIII.

Of Water in the State of Ice.

I HAVE ſhewn you, that water is in a fluid ſtate only on account of it's combination with fire; that if it loſes the fire, which is thus combined with it, it's particles cohere together, and form a hard ſubſtance called ice.

Water in freezing parts with the fire, with which it was combined. If a thermometer be immerſed in a veſſel of freezing water, the mercury will riſe ſome degrees above 32°, while another thermometer, in the open air, will remain fixed at or ſome degrees below that point; part of the fire which was fixed in the water being diſengaged, eſcapes into the air when it aſſumes a ſolid form. A ſimilar diſengagement of fire is perceived in the cryſtallization of ſalts. On the other hand, when ice melts, it combines itſelf with a conſiderable quantity of fire, which at the ſame time does not increaſe the temperature, which you may prove by this experiment. Let there be a pound of ice at 32°, mix a pound of water at 172 therewith, and, in a few moments, the ice will be melted, and the temperature of the mixture will be 32°; a quantity of fire, which raiſed the thermometer 140° (140+32=172), was abſorbed by and combined with the ice to give it a fluid form; but the fire, thus abſorbed, does not produce any effect upon the thermometer.

The fire, which the water abſorbs, when it acquires a fluid form, is again ſeparated from it by congelation; for if a pound of water at 32° be mixed with an equal quantity of ice at 4°, nearly $\frac{1}{5}$ of the water will be frozen, and the temperature of the mixture will be 32. Now, in this experiment, the ice is raiſed from 4° to the freezing point, that is, 28°. It is therefore plain, that by the congelation of ⅕ of a pound of water, a ſufficient quantity of fire is evolved to raiſe a pound of ice 28 degrees: now five times 28 is 140°, ſo that the fire, which is extricated by congelation, is preciſely equal to that which is abſorbed by the melting ice. Meſſrs. Lavoiſier and de la Place have given us this general idea of this phenomenon. *The heat, neceſſary to melt ice, is equal to three-fourths of that which would elevate the ſame weight of water, at the freezing point, to that of boiling water.*

The external air promotes the formation of ice; water in a cloſe veſſel freezes very ſlowly; but if expoſed to air of the ſame temperature, ice will very ſoon be formed. A ſimilar phenomenon is ſaid to be obſerved in the cryſtallization of ſalts; many ſaline ſolutions, which will remain in that ſtate in cloſe veſſels, diſplay cryſtals almoſt as ſoon as you open the mouth of the veſſel, and expoſe them to the contact of the atmoſphere.

Gentle motion, or a ſlight agitation of the fluid, facilitates it's converſion into ice: nearly in the ſame manner, ſome ſaline ſolutions are determined to cryſtallization by a ſlight agitation. It is probable, that the two above-mentioned circumſtances facilitate the ſeparation of the combined fire from the water.

Boiled water may be brought a greater number of degrees below the freezing point without congealing, than unboiled water, which contains more air.

Subſtances, which leſſen the *tranſparency* of water, render it at the ſame time more difficult to be cooled below 32° without freezing, and diſpoſe it to ſhoot more readily into ice.

Foreign ſubſtances chemically combined, or diſſolved in water, do not take away it's property of being cooled, though they alter the degree at which that property commences.

Striking the bottom of a tumbler with cooled water againſt a board, will produce inſtant congelation; when ſtirring the water, or ſhaking it in the hand, will have no effect. The moſt certain method of bringing on congelation is, that of rubbing a bit of wax on the ſide of the tumbler, but under the water; a particular roughneſs in the motion is felt, and a cruſt of ice is immediately perceived under the wax upon the glaſs.

Theſe methods ſucceed beſt in proportion as the water is more cooled below the freezing point; unleſs the cooling amounts to 4 or 5 degrees, the friction from the wax is often in vain.

When water is cooled below the freezing point, the contact of the leaſt particle of ice will make it inſtantly congeal; the glacial cryſtals ſhooting all through the liquor, from the ſpot where the ice touches, till the whole comes up to the freezing point. Few experiments of the minute kind afford a more ſtriking ſpectacle than this, eſpecially when the water has been cooled, nearly as much as poſſible, below the freezing point; both from the beautiful manner in which the cryſtals ſhoot through it, and the rapidity with which the mercury in the thermometer immerſed in it, runs through a ſpace of 10 or 11 degrees, ſtopping and fixing always at 32 in pure water.

The effect of ice, in haſtening congelation, explains ſome phenomena. In a calm day, when the temperature of the air was about 20°, two veſſels, with diſtilled water, were expoſed to the cold; one of them was ſlightly covered with paper, the other was left open; the former bore to be cooled many degrees below the freezing point, whilſt a cruſt of ice always formed on the ſurface of the other, before the thermometer immerſed in the middle of it, came to the freezing point; moſt probably ariſing from the frozen particles, which, in froſty weather, are generally floating in the air.

Oil ſpread over the ſurface of water has been found to prevent it from freezing, when other water ſimilarly expoſed, has had a cruſt of ice upon it; the oil preventing the frozen particles from coming in contact with the water. In frigorific mixtures the congelation is often brought on by raiſing the immerſed thermometer a little out of the water, and lowering it again, ſome of the adhering water having frozen on the ſtem.

To inſure the greateſt degree of cold in water without freezing, you muſt cool it in a very gradual manner, keeping the cold of the frigorific mixture regularly, only two or three degrees below that of the water. Sudden cooling may be conſidered as one of the cauſes which haſten congelation. Metallic or too thin veſſels are not proper for theſe experiments, as they tranſmit fire too readily. The frigorific mixture ſhould be kept a little below the edge of the water in the tumbler, otherwiſe the congelation quickly begins at that place.

Fahrenheit cooled water 15 degrees below it's common freezing point without freezing; Mr. de Luc to 14°. It is not improbable, that if water could be thoroughly purged of air, it might be cooled 18° below the freezing point without congelation. Other fluids will bear to be cooled much more below their proper point of congelation.

When water is nearly congealed, it augments in bulk, as we ſhall ſhew you by this ſimple experiment. I ſhall take this tube filled to E, and plunge the bulk thereof in the mixture of ſalt and ice; you will obſerve that the water at firſt riſes in the tube, on account of the ſudden contraction of the bulb on being immerged in this cold medium; the water now contracted in it's turn falls again, and will remain for ſome time at the ſame point; in a little time it will begin to expand; it has now riſen to H, and ſoon will riſe with ſome violence much higher; it is now got to I; the water in the bulb you ſee loſes it's tranſparency, and grows cloudy, and is freezing during the congelation; and while the ice is hardening, the water riſes in the tube; it now runs over it.

This expanſive force of ice is very great, as you will be convinced, by the detail of a few intereſting experiments. The Rev. Mr. Jones made a long cylindrical metal box with a ſtrong rim; to this he applied a cover, fitting them with great exactneſs by grinding them one upon the other in a turning-lathe. He then prepared ſome water, firſt by boiling, and ſecondly by exhauſting the air from it, which was ſo far effected, that when cold it did not yield the leaſt bubble of air, on trying it by the air-pump. He filled the box with water, till it ſtood convex above the rim; and having applied a wet leather to the cover, he ſcrewed it down firmly upon the box with four iron ſcrews. In this ſtate, it is probable, the box could not have been ſeparated from it's cover by a weight leſs than half a ton. He plunged the whole into a freezing mixture, in leſs than half an hour the water was froze into a ſolid maſs, and as it's bulk increaſed, the three ſcrews were forced by the violence of the preſſure, and the cover was raiſed up on one ſide a quarter of an inch above the rim.

To meaſure this force with more exactneſs, the ſame gentleman made another experiment, uſing the ſame box, and filling it as before with water purged of it's air, and being covered, but not ſcrewed down; it was placed upon an oaken pedeſtal, which had for it's baſe a flat hewn ſtone of about a foot ſquare. The ſhorter arm of a very ſtrong lever was made to preſs upon the cover; this lever was compounded with two more to increaſe the power; at the extremity of the longeſt arm of the moſt remote lever a cord was faſtened, which ran over a pulley, and had a weight of 28lb.; by all theſe combined, the cover of the box was preſſed with a force of above 2296lb.; while it was ſo preſſed down, the water within it was froze, and the agent by which the water was congealed overcame the whole force of the machine. The experiment, however, was not complete; for when the water began to freeze, and the cover of the box to be raiſed from the rim, the *ground yielded* under the preſſure, and the flat ſtone, which ſerved as a baſe to the pedeſtal, ſunk a little below it's firſt poſition; by this means the force was at firſt ſpent upon the ground, and did not take place in the machine till the ground would give way no more. It was, however, ſo ſenſibly perceived in the machine, as to prove that it was at leaſt ſuperior to *one ton two hundred and ninety-ſix pounds.* The box contained 5 $\frac{6}{10}$ cubic inches. May not this force proceed from fire, not as giving, but as reſtoring an equilibrium, which has been interrupted? For light and fire may have powerful effects in nature, where they give no ſenſible heat.

By the expanſive force of ice, Huyghens burſt an iron tube of half an inch in thickneſs. In the experiments of the academy del cimento, bombſhells and the ſtrongeſt veſſels being filled with water, were burſt in pieces by the fluid on it's congelation.

When water is congealed into ice, a great number of bubbles are produced and impriſoned in it; as theſe bubbles are produced in the act of freezing, they extend the bulk of it's water, and render the ice ſpecifically lighter, and capable of floating thereon. That theſe bubbles are, in a great meaſure, the cauſes of this expanſion, is clear from the experiments of Marriotte and Mairan, who found ice made with water, well purged of air, ſenſibly heavier than that formed from the ſame quantity of common water. According to Mairan, ice formed of water, purged of air, exceeded $\frac{1}{32}$ in bulk the volume of water which formed it; while ice made from water, not purged of air, exceeds the water $\frac{1}{8}$ or $\frac{1}{10}$ in bulk; therefore floats with about one tenth part of it's thickneſs out of, or above the water that bears it. From hence you may infer the amazing thickneſs of the ice in the northern ſeas, where the portion above the ſurface is higher than the maſts of the talleſt veſſels.

When a tract of ice in ſtrong maſſes is ſpread over the ground, and other ice continues to be formed underneath, where there is not room for it's expanſion, as in the glaciers of Switzerland, the ice underneath ſometimes expands with ſuch force as to rend the ſuperior ſtrata with violent exploſions. In the froſty climates of the polar regions, theſe exploſions are frequent, and ſometimes as loud as a cannon.

The expanſive force of ice is applied on ſeveral occaſions to ſave the labour of man, and perform ſuch things as are beyond the reach of art. Blocks of ſlate-ſtone, which is formed in thin plates or ſtrata, not ſeparable by a tool, are taken out of the quarry and expoſed to rain, which ſoaking into the pores of the ſtone is there frozen into ice, which, by it's expanſion, breaks the ſtone into thin plates. In the iron works, they ſometimes, in order to break an old bomb-ſhell, fill it with water, then faſten up the vent and expoſe it to the froſt, which burſts it into pieces without farther trouble. If you expect, therefore, that any liquor will freeze, and wiſh to preſerve your veſſel, leave room therein ſufficient for this accidental extenſion.

The effects of this expanſion are obſervable in a thouſand phenomena. Trees are burſt, rocks are rent; walnut, aſh, and oak-trees, are ſometimes cleft aſunder, and this with a noiſe like the exploſion of fire-arms.

Nor are the effects of extreme cold leſs wonderful; metallic ſubſtances will then bliſter the ſkin like red-hot iron; the air, when drawn in, hurts the lungs, and excites coughing.

When the French mathematicians wintered at Tornea, in Lapland, the external air, when ſuddenly admitted into their rooms, converted the moiſture of the air into whirls of ſnow. Their breaſt ſeemed to be rent when they breathed it, and the contact of it was intolerable to their bodies; and the aqueous parts of ſpirit of wine, which had not been highly rectified, burſt ſome of their thermometers.

Extreme cold often proves fatal to animal life; 7000 Swedes periſhed at once in attempting to paſs the mountains, which divide Norway from Sweden. In caſes of extreme cold, the perſon attacked firſt feels himſelf extremely chill and uneaſy, he begins to turn liſtleſs, is unwilling to walk or uſe the exerciſe neceſſary to keep him warm, and at laſt turns drowſy, ſits down to refreſh himſelf with ſleep; but wakes no more. An inſtance of this was ſeen at Terra del Fuego, where *Dr. Solander*, with ſome others, having taken an excurſion up the country, the cold was ſo intenſe as to kill one of their company. The doctor himſelf, though he had warned his companions of the danger of ſleeping in that ſituation, yet could not be prevented from making that dangerous experiment himſelf; and though he was awaked with all poſſible expedition, his body was ſo much ſhrunk in bulk, that his ſhoes fell off his feet, and it was with the utmoſt difficulty he was recovered.

In thoſe parts of the world, where vaſt maſſes of ice are procured, the accumulation thereof by abſorbing the fire from the atmoſphere, occaſions great *ſterility* in the neighbouring countries, as is particularly the caſe with the iſlands of Iceland, Greenland, Statenland, &c.

Ice is ſubject to a conſtant diminution of it's weight when expoſed to the common air. Mr. Boyle expoſed two ounces of ice to a ſharply freezing air a little before midnight, and found it in the morning diminiſhed 10 grains in weight. In long continued frosts, the ice formed in ponds, and other ſmall collections of water, is ſenſibly diminiſhed every day, and often wholly evaporated; and a fall of ſnow may be ſeen conſiderably waſted in a few days in the ſevereſt ſeaſon. The principal cauſe of this loſs of weight ſeems to be the inceſſant action and abraſion of the air upon the ſurface of the ice.

Notwithſtanding this loſs of weight to which both ice and ſnow are ſubject in the *coldeſt* weather, and the thaw which they experience in the hotteſt, ſome have doubted, whether the quantity of congealed water be not an increaſing quantity. A philoſopher,* well acquainted with the nature of the Alps, expreſſes himſelf upon the ſubject in the following manner: " One cannot doubt concerning the increaſe of all the glaciers of the Alps; *their very exiſtence* is a proof, that in preceding ages, the quantity of ſnow which has fallen during the winter, has exceeded the quantity melted during the ſummer. Now, not only the ſame cauſe ſtill ſubſiſts; but the cold, occaſioned by the maſs of ice already formed, ought to augment it ſtill farther, and thence more ſnow ought to fall, and a leſs quantity of it be melted."

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* Mr. De Luc.

Though this be admitted, it by no means follows that there is an annually increaſing quantity; for, beſides the heat of the air in ſummer, there is another cauſe, which tends to prevent any indefinite augmentation of congealed water,—*the internal heat of the earth.* The general heat of the ſprings of water, ſituated deep in the bowels of the earth, is 48 degrees. In mountainous countries it may be ſomewhat leſs, but ſufficient notwithſtanding for the purpoſe here mentioned. When the ſnow, incumbent on any ſpot of ground, is but thin, it may ſo far cool the earth, that the internal heat may not be able to diſſolve it; but when the bed is *thick* enough to protect the earth from the influence of the atmoſpherical cold, that ſurface of the earth may, even in the coldeſt winters, receive more heat from the earth, than cold from the atmoſphere, and be therefore diſſolved at all ſeaſons of the year. *

This reaſon is corroborated by fact; for it is ſaid, that ſtreams of water iſſue from the bottom of the *glaciers* in the *Alps*, in the greateſt ſeverity of winter; ſo that whether the internal heat of the earth be admitted or not, as a cauſe ſufficient to explain the phenomenon, a conſtant thaw of the ice or ſnow, which is contiguous to the ſurface of the earth in the Alps, cannot be denied; and this, added to other cauſes, may render it probable, that the quantity of congealed water has it's limit, even in the coldeſt country.

Ice appears to be a kind of confuſed cryſtallization. Mr. De Mairan obſerved, that the needle-formed cryſtals of ice unite in an angle of 60 or 120°. If a piece of ice, which contains water in it's internal part, be broken, the water runs out, and the internal cavity is found to be lined with beautiful tetrahedral priſms. Theſe priſms are often articulated and croſſed. When it ſnows at Moſcow, and the atmoſphere is not too dry, the air is obſerved to be loaded with beautiful cryſtallizations regularly flattened, and as thin as a leaf of paper. They conſiſt of an union of fibres which ſhoot from the ſame center to form ſix principal rays; theſe rays divide themſelves into extremely ſmall blades. Mr. Macquart has obſerved ſeveral of theſe flattened radii, which were ten lines in diameter.

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* Watſon's Chemiſtry, vol. iii. p. 184.

Hail and ſnow are modifications of ice. Hail is probably produced by a ſudden diſengagement of the fire by which water is rendered liquid, and is generally accompanied by thunder. *Hail*, *ſnow*, and *ice*, are wonderful images of the great operations in nature; and if your ſenſes had not acquainted you how theſe things are created out of ſomething, and are themſelves only the properties of fire, air, and water, brought out of a prior ſtate into ſuch a compaction and creation as is called ſnow, hail, and ice, philoſophy would have left you as ignorant of their nature, as it is of moſt material ſubſtances. Mr. Chaptal relates the following curious obſervation, made by himſelf at Montpellier, Oct. 29, 1786. "On that day four inches of water fell at Montpellier, a violent exploſion of thunder was heard about four in the afternoon, which appeared to be very near, and was accompanied by a moſt violent ſhower of hail. At this inſtant, a druggiſt, who was employed in preventing the miſchief occaſioned by the filtration of water through the wall, was greatly aſtoniſhed by perceiving the water that came through the wall inſtantly changed into ice. He called in ſeveral of his neighbours to partake of his ſurprize. Mr. Chaptal viſited the place about a quarter of an hour afterwards, and found

about

about ten pounds of ice at the foot of the wall: he was well aſſured it could not have paſſed through the wall, which did not exhibit any crack. Did the ſame cauſe which determined the formation of hail in the atmoſphere, act equally in the cellar?"

A maſs of ice formed by a ſlow congelation, appears very homogeneous, and ſufficiently tranſparent for a ſmall diſtance from the ſurface firſt frozen; but in the interior parts, and particularly towards the middle, there is a conſiderable number of bubbles of air. A quick congelation ſpreads theſe bubbles indifferently through the whole maſs, which becomes therefore almoſt opake, being compoſed of ſmall parts of different denſities; and the upper ſurface is more rough and irregular than when the congelation has been ſlow and gradual.

The ice of running waters is differently formed from that of ſtanding waters; in theſe the ſurface is firſt froze, and thickens gradually by freezing one ſtratum of water after another; and it is carried on much more expeditiouſly than when it is in motion.

When the cold is ſufficient, the water freezes on the edges of a river. The ice thus formed is, however, often broken and carried away by the current; more ice is then formed, which is again broken off, and ſo on. The cakes of ice thus formed, are at firſt very thin, and eaſily broken by the firſt ſhock, ſo that very few remain whole, but are broken in a thouſand pieces. Thus in a little time the river is covered with ſmall pieces of ice (that the leaſt obſtacle ſtops) floating down it's ſtream. Theſe by degrees, and from a variety of circumſtances accumulate in ſize and number; and the ice thus formed is very irregular and opake, and mixed with a variety of ſmall heterogeneous ſubſtances, as bits of ſtraw, herbs, &c. which had attached themſelves to the pieces of ice. By a continual increaſe in ſize by the various obſtacles to be met with in the courſe of a river, ſuch as bridges, &c. theſe cakes are at laſt ſo joined as to cover the river. In very ſevere froſts, and very cold climates, rivers have been known to be froze over with great rapidity. Dr. Goldſmith mentions having ſeen the Rhine frozen at one of it's moſt precipitate cataracts, and the ice ſtanding in glaſſy columns like a foreſt of large trees, the branches of which have been lopt away. So hard does the ice become in cold countries, that in 1740, a palace of ice was built at Peterſburg, after a very elegant model, and in juſt proportions of Auguſtan architecture. It was 52 feet long, and 20 feet high. The materials were quarried from the ſurface of the river Neva, and the whole ſtood gliſtening againſt the ſun with a brilliancy almoſt equal to his own. To increaſe the wonder, 6 cannons of ice, and two bombs, all of the ſame materials, were planted before this extraordinary edifice: the cannon were three pounders, they were charged with gunpowder, and fired off; the ball of one pierced an oak plank 2 inches thick at ſixty paces diſtance, nor did the piece burſt with the exploſion.

In the northern parts of the world ſolid bodies are liable to be hurt by the froſt. Timber is often apparently frozen, and exceedingly difficult to be ſawed. Marle, chalk, and other leſs ſolid terreſtrial concretions, are often ſhattered by long and durable froſts. Metals are contracted by froſt: thus an iron tube 12 feet long, upon being expoſed to the air in a froſty night, loſt two lines of it's length. The expanſion of water I have already mentioned to you. Trees are often deſtroyed by froſt, and appear as if burnt by the moſt exceſſive heat.

Froſt generally proceeds from the upper parts of a body downwards; but how deep it will reach in the earth is not eaſily known, as this depth will vary from a variety of cauſes, as the duration of the froſt, the texture of the ground, &c. After a hard froſt of ſome days, Mr. Boyle dug in an orchard where the ground was level and bare, and found the froſt had ſcarce reached 3 inches and a half below the ſurface. Nine or ten ſucceſſive froſty nights froze the ground in the orchard only to the depth of 8 inches and a half. In a garden at Moſcow, the froſt in a hard ſeaſon only penetrated 2 feet. Water, like the earth, ſeems not diſpoſed to receive any very intenſe degree of cold at a conſiderable depth or diſtance from the air; the vaſt maſſes of ice found in the northern ſeas being only many flakes and fragments, which, ſliding under each other, are cemented together by the congelation of the intercepted water.

The great power of froſt on vegetables is a thing ſufficiently known; but the difference between the *froſts* of a *ſevere winter*, and thoſe of ſpring mornings, have been but little attended to; you will, however, find it a ſubject very worthy of your attention.

The froſts of a *ſevere winter* are much more terrible than thoſe of the *ſpring*, as they bring on a privation of all the products of the tenderer parts of the vegetable world; but they are not *frequent*, ſuch winters happening but once in an age; but the froſts of the ſpring are more injurious, as they are repeated every year.

In regard to trees, the great difference is this, that the froſts of a ſevere winter affect their wood, their trunks, and the large branches; whereas thoſe of the ſpring have only power to hurt the buds.

The winter froſts happen at a time when moſt of the trees have neither leaves, flowers, nor fruits upon them, and have their buds ſo hard as to be proof againſt ſlight injuries of the weather, eſpecially if the preceding ſummer has not been *too* *wet.* Hard froſts, which happen late in the winter, cauſe very great injuries even to thoſe trees which they do not deſtroy.

It is not *the ſevereſt cold or moſt fixed froſt that does the greateſt injury to vegetables.* Though this obſervation is directly oppoſed to popular opinion, it will be found not leſs true, nor any way repugnant to reaſon. It is *humidity* that makes froſt fatal to vegetables, and therefore every thing that can occaſion humidity expoſes them to theſe injuries. It is well known, that vegetables always feel the froſt very deſperately in low places where there are fogs. The plants which ſtand by a river ſide are often deſtroyed by the ſpring and autumnal froſts; whilſt thoſe of the ſame ſpecies, which ſtand in a drier place, ſuffer but little, if at all. The low and wet parts of foreſts produce worſe wood than the high and drier. The coppice wood in wet and low parts of common woods, though it puſh out at firſt more vigorouſly than that of other places, yet never comes to ſo good a growth; for the froſt of the ſpring killing theſe early top ſhoots, obliges the lower parts of the trees to throw out lateral branches. Froſt ſeldom hurts the late ſhoots of vine or flower buds, except when it follows heavy dews, or a long rainy ſeaſon, and then it never fails to do great miſchief.

Froſt does more miſchief on newly cultivated ground than in other places, becauſe the vapours find an eaſier paſſage there than from other places. Trees newly cut ſuffer more than others by ſpring froſts, becauſe they ſhoot more vigorouſly. Side ſhoots of trees are more ſubject to ſuffer from ſpring froſts, than thoſe at the top; in general, the effects of the ſpring froſts are much greater near the ground than elſewhere.

On the ſame principles you may explain why the ſouth ſides of trees are more damaged by a ſevere froſt than the north. Great damage is alſo done to the weſtern ſide of trees and plantations, when after a rain with a weſt wind, the wind turns about to the north at ſun-ſet, which is common in ſpring; or when the eaſt blows upon a thick fog before ſun-riſing.

In the ſtate of the atmoſphere we denominate a froſt, there is an intimate union between the air and the water in the air; therefore except in high latitudes, froſty weather is generally *clear.* When ſuch an union takes place, either in winter or ſummer, the atmoſphere is inclined to *abſorb fire*, and conſequently to produce froſt. Thus in clear ſettled weather, even in ſummer, though the day may be exceſſive hot, yet the mornings and evenings are extremely cold.

The air in froſty weather, or clear dry weather, being always ready to abſorb fire from every ſubſtance in contact, muſt of courſe abſorb part of that contained in the vapour, which floats in it's boſom.

Though vapour is capable of becoming much colder than water without being frozen, yet by a continual abſorption it muſt at laſt part with it's *latent fire*; i.e. what is eſſential to it's exiſtence as vapour, and without which it is no longer vapour, but water or ice. When a froſt has acquired a certain degree of intenſity, then the vapours every where diſperſed in the air give out their latent fire, the atmoſphere becomes clouded, the froſt either goes off or becomes milder, and the vapour deſcends in rain, hail, or ſnow, according to the diſpoſition of the atmoſphere.

TO MAKE ICE.

In many countries the warmth of the climate renders ice not only a deſirable, but even a neceſſary article; ſo that it becomes an object of ſome conſequence to fall upon a ready and cheap method of procuring it. Though the cheapeſt method hitherto diſcovered, ſeems to be that by means of ſal-ammoniac or Glauber's ſalt; yet it may not be amiſs to take notice of ſome attempts made by Mr. Cavallo, to diſcover a method of producing a ſufficient degree of cold for this purpoſe by the *evaporation* of volatile liquors. He found, however, in the courſe of theſe experiments, that ether was incomparably ſuperior to any other fluid in the degree of cold it produced. The price of the liquor naturally induced him to fall upon a method of uſing it with as little waſte as poſſible.

The apparatus for uſing the leaſt poſſible quantity of ether for freezing water, conſiſts in a glaſs tube terminating in a capillary aperture, which is to be fixed upon the bottle containing the ether. Round the lower part of the neck ſome thread is wound, in order to let it fill the neck of the bottle. When the experiment is to be made, the ſtopper of the bottle containing the ether is to be removed, and the tube juſt mentioned put in it's room. The thread round the tube ought alſo to be previouſly moiſtened with water before it is put in the neck of the bottle, in order the more effectually to prevent the eſcape of the ether betwixt the neck of the phial and tube. Holding then the bottle by it's bottom, and keeping it inclined, the ſmall ſtream of ether iſſuing out of the aperture of the tube, is directed upon the ball of the thermometer, or upon a tube containing water or other liquor that is required to be congealed. As ether is very volatile, and has the remarkable property of increaſing the bulk of air, there is no aperture requiſite to allow the air to enter the bottle while the liquor flows out. The heat of the hand is more than ſufficient to force out the ether in a continued ſtream at the aperture.

In this manner, by throwing the ſtream of ether upon the ball of a thermometer in ſuch a quantity, that a drop might now and then, every 10 ſeconds for inſtance, fall from the bulb of the thermometer, Mr. Cavallo brought the mercury down to 3°, or 29° below the freezing point, when the atmoſphere was ſomewhat hotter than temperate. When the ether is very good, i. e. capable of diſſolving elaſtic gum, and has a ſmall bulb, not above 20 drops of it are required to produce this effect, and about two minutes of time; but the common ſort muſt be uſed in greater quantity, and for a longer time; though at laſt the thermometer is brought down by this very nearly as low as by the beſt ſort.

The proportion of ether requiſite to congeal water, ſeems to vary with the quantity of the latter; that is, a large quantity of water ſeems to require a proportionably leſs quantity of ether to freeze it than a ſmaller one. "In the beginning of the ſpring (ſays Mr. Cavallo) I froze a quarter of an ounce of water with about half an ounce of ether; the apparatus being larger, though ſimilar to that deſcribed above. Now as the price of ether ſufficiently good for the purpoſe, is generally about 18 pence or two ſhillings per ounce; it is plain, that with an expence under two ſhillings, a quarter of an ounce of ice, or ice cream, may be made in every climate, and at any time, which may afford great ſatisfaction to thoſe perſons, who, living in places where no natural ice is to be had, never ſaw or taſted any ſuch delicious refreſhment. When a ſmall piece of ice, for inſtance, of about ten grains weight, is required, the neceſſary apparatus is very ſmall, and the expence not worth mentioning. A ſmall box four inches and a half long, two inches broad, and one and a half deep, contains all the apparatus neceſſary for this purpoſe; viz. a bottle capable of containing about one ounce of ether; two pointed tubes, in caſe one ſhould break; a tube in which the water is to be frozen, and a wire. With the quantity of ether contained in this ſmall and very portable apparatus, the experiment may be repeated about ten times. A perſon who wiſhes to perform ſuch experiments in hot climates, and in places where ice is not eaſily procured, requires only a larger bottle of ether. beſides the whole apparatus deſcribed above.

TO PRODUCE A GREAT DEGREE OF COLD.

The power of producing cold belongs particularly to bodies of the ſaline claſs. In a paper of the Philoſophical Tranſactions, Mr. Geoffroy gives an account of ſome remarkable experiments with regard to the production of cold. Four ounces of ſal-ammoniac diſſolved in a pint of water, made his thermometer deſcend two inches and three quarters in leſs than fifteen minutes. An ounce of the ſame ſalt put into four or five ounces of diſtilled water, made the thermometer deſcend two inches and a quarter. Half an ounce of ſal-ammoniac mixed with three ounces of ſpirit of nitre, made the thermometer deſcend two inches and five lines; but on uſing the ſpirit of vitriol inſtead of nitre, it ſunk two inches and ſix lines. In this laſt experiment it was remarked, that the vapours raiſed from the mixture had a conſiderable degree of heat, though the liquid itſelf was ſo extremely cold. Four ounces of ſalt-petre mixed with a pint of water, ſunk the thermometer one inch three lines; but a like quantity of ſea-ſalt ſunk it only two lines. Acids always produced heat, even common ſalt with it's own ſpirit. Volatile alkaline ſalts produced cold in proportion to their purity, but fixed alkalines heat.

If, inſtead of making theſe experiments, however, with fluid water, we take it in it's congealed ſtate of ice, or rather ſnow, degrees of cold will be produced vaſtly ſuperior to any we have yet mentioned. A mixture of ſnow and common ſalt ſinks Fahrenheit's thermometer to 0; pot-aſhes and powdered ice ſink it eight degrees farther; two effuſions of ſpirit of ſalt on pounded ice ſink it more than $14\frac{1}{2}$° below 0. This is the ultimate degree of cold that the mercurial thermometer will meaſure, becauſe the mercury itſelf then begins to congeal; and therefore we muſt afterwards have recourſe to ſpirit of wine, naptha, or ſome other fluid which will not congeal. The greateſt degree of cold hitherto producible by artificial means has been 80° below 0; which was done at Hudſon's Bay by means of ſnow, and vitriolic acid, the thermometer ſtanding naturally at 20° below 0. Greater degrees of cold than this have indeed been ſuppoſed. Mr. Martine, in his treatiſe on heat, relates, that at Kirenga in Siberia, the mercurial thermometer ſunk to 118° below 0; and Profeſſor Brown at Peterſburg, when he made the firſt experiment of congealing quickſilver, fixed the point of congelation at 350° below 0; but Dr. Black, as ſoon as the experiment was made known in this country, obſerved, that in all probability the point of congelation was far above this. His reaſons for ſuppoſing this to be the caſe were, that the mercury deſcended regularly only to a certain point, after which it would deſcend ſuddenly and by ſtarts 100 degrees at a time. This, he conjectured, might proceed from the irregular contraction of the metal after it was congealed; and he obſerved, that there was one thermometer employed in the experiment which was not frozen, and which did not deſcend ſo low by a great many degrees. Experience has ſince verified his conjecture; and it is now generally known, that 40° below 0 is the freezing point of quickſilver.

Since the diſcovery of the poſſibility of producing cold by artificial means, various experiments have been made on the efficacy of ſaline ſubſtances in this way; all of which, when properly applied, are found to have a conſiderable degree of power. Dr. Boerhaave found, that both ſal-ammoniac and nitre, when well dried in a crucible, and reduced to fine powder, will produce a greater degree of cold than if they had not been treated in this manner. His experiments were repeated by Mr. Walker, apothecary to the Radcliffe Infirmary in Oxford, with the ſame reſult: but he found, that his thermometer ſunk 32° by means of a ſolution of ſal-ammoniac; when Boerhaave's, with the ſame, fell only 28°. Nitre ſunk it 19°. On mixing the two ſalts together, he found that the power of producing cold was conſiderably increaſed. By equal parts of theſe ſalts, he cooled ſome water to 22°, the thermometer ſtanding at 47° in the open air. Adding to this ſome powder of the ſame kind, and immerſing two ſmall phials in the mixture, one containing boiled and the other unboiled water, he ſoon found them both frozen, the unboiled water freezing firſt.

The moſt remarkable experiment, however, was with ſpirit of nitre poured on Glauber's ſalt, the effect of which was found to be ſimilar to that of the ſame ſpirit poured on ice or ſnow; and the addition of ſal-ammoniac rendered the cold ſtill more intenſe. The proportions of theſe ingredients recommended by Mr. Walker, are concentrated nitrous acid two parts by weight, water one part; of this mixture cooled to the temperature 18 ounces, of Glauber's ſalt a pound and an half avoirdupois, and of ſal-ammoniac 12 ounces. On adding the

Glauber's ſalt to the nitrous acid, the thermometer fell from 50° to —1°, or 52 degrees; and on the addition of the ſal-ammoniac, to —9°. Thus Mr. Walker was able to freeze quickſilver without either ice or ſnow, when the thermometer ſtood at 45°. For the experiment four pans were procured of different ſizes, ſo that one might be put within the other. The largeſt of theſe pans was placed in a veſſel ſtill larger, in which the materials for the ſecond frigorific mixture were thinly ſpread in order to be cooled; the ſecond pan, containing the liquor, viz. the vitriolic acid properly diluted, was placed in the largeſt pan; the third pan, containing the ſalts for the third mixture, was immerſed in the liquor of the ſecond pan; and the liquor for the third mixture was put into wide-mouth phials, which were immerſed in the ſecond pan likewiſe, and floated round the third pan; the fourth pan, which was the ſmalleſt of all, containing it's cooling materials, was placed in the midſt of the ſalts of the third pan. The materials for the firſt and ſecond mixtures conſiſted of diluted vitriolic acid and Glauber's ſalt; the third and fourth of diluted nitrous acid, Glauber's ſalt, and ſal-ammoniac, in the proportions above-mentioned. The pans being adjuſted in the manner already mentioned, the materials of the firſt and largeſt pan were mixed: this reduced the thermometer to 10°, and cooled the liquor in the ſecond pan to 20°, and the ſalts for the ſecond mixture, which were placed underneath in the large veſſel, nearly as much. The ſecond mixture was then made with the materials thus cooled, and the thermometer was reduced to 3°. The ingredients of the third mixture, by immerſion in this, were cooled to 10°, and when mixed, reduced the thermometer to —15°. The materials for the fourth mixture were cooled by immerſion in this third mixture to about —12°. On mixture they ſunk the mercury very rapidly, and ſeemingly below—40°, though the froth occaſioned by the ebullition of the materials, prevented any accurate obſervation. The reaſon why this laſt mixture reduced the thermometer more than the third, though both were of the ſame materials, and the latter of a lower temperature, was ſuppoſed to have been partly becauſe the fourth pan had not another immerſed in it to give it heat, and partly becauſe the materials were reduced to a finer powder.

The experiments were repeated with many variations; but only one mixture appeared to Dr. Beddows, by whom the account was communicated to the Royal Society, to be applicable to any uſeful purpoſe. This is oil of vitriol diluted with about an equal quantity of water; which, by diſſolving Glauber's ſalt, produces about 46° of cold, and by the addition of ſal-ammoniac, becomes more intenſe by a few degrees. At one time, when Mr. Walker was trying a mixture of two parts of oil of vitriol and one of water, he perceived, that at the temperature of 35°, the mixture coagulated as if frozen, and the thermometer became ſtationary; but on adding more Glauber's ſalt, it fell again in a ſhort time: but leſs cold was produced than when this circumſtance did not occur, and when the acid was weaker. The ſame appearance of coagulation took place with other proportions of acid and water, and with other temperatures.

It is obſervable, that this effect of Glauber's ſalt in producing cold, took place only when it was poſſeſſed of it's water of cryſtallization; and thus the mineral alkali alſo augmented the cold of ſome of the mixtures: but when the water of cryſtallization was diſſipated, neither of them had any effect of this kind.

AN ABSTRACT OF M. DE LUC'S VIEW OF GENERAL CHEMISTRY, DEDUCED FROM CONSIDERING THE CHANGE OF ICE INTO WATER, AND WATER INTO ICE.

There is no phenomenon more important than the change of *ice* into *water*, and of *water* into *ice*. Though I have already conſidered this phenomenon, I ſhall here again, after M. de Luc, analyſe it more particularly, in order to ſhew you, that it includes the important baſis of *general chemiſtry*. The various operations of chemiſtry may be reduced to the *uniting* or *ſeparating* of ſubſtances: their general immediate cauſe ariſes from the different tendencies of the particles which compoſe thoſe different ſubſtances: and the changes which happen in theſe phenomena are produced by the changes that the *particles* undergo in their compoſition. Now as the phenomena of *water* and *ice* include all theſe different kinds of modifications, they will furniſh you with a clear and very important idea of the kind of change which is the ſource of *chemical phenomena*.

Now with reſpect to ice: 1. It's *particles* cannot be *ſeparated* without a ſenſible effort. 2. When broken, the portions thereof, although brought within the ſmalleſt poſſible *diſtance* of each other, ſhew no *tendency* to *unite*. 3. When fragments of ice are laid in *heaps*, the reſpective *adherence* of the particles, joined to their reſiſtance to motion, makes them remain in the ſame poſition in which they have been placed. Theſe are ſtrongly marked chemical properties, and the ſubſtance cannot be deprived of them, unleſs the *particles* undergo an eſſential change.

Water, if you were only to judge of it by *weight*, would be ice itſelf, for the transformation is made without any diſcernible change in *weight*;

though very great changes have taken place in the *ponderable* particles; for, 1. They may be *ſeparated* with the greateſt eaſe, their reſiſtance to ſeparation being almoſt inſenſible. 2. They have a tendency towards each other even at a ſenſible diſtance; hence ſmall maſſes, when free, coaleſce, and form a ſpherical drop, the moment they touch; and this is not the effect of *gravity*, but contrary to it. 3. Theſe new *particles* ſlide ſo eaſily one over the other, that, excepting the above-mentioned ſmall maſſes, they cannot now be laid in *heaps*; but yield immediately to the efforts of gravity, and always become *level*. Let us now conſider how theſe changes in the particles of ice are accounted for. " Philoſophers are unanimous in allowing that theſe changes are occaſioned by *fire*, a ſubſtance without weight. The quantity of this ſubſtance that produces this effect, is ſufficiently characterized by it's peculiar properties; but after this change, theſe properties are no longer exerciſed, becauſe the particles of fire are combined with thoſe of *ice*. It is this combination that occaſions the chemical changes juſt deſcribed. Now theſe changes are as eſſential with reſpect to phyſical principles, as any other in the art of chemiſtry; ſo that unleſs eſtabliſhed facts ſhould lead us to aſſign a ſenſible *weight* to other ſubſtances which modify theſe effects in water, this example alone would authoriſe us in conſidering theſe new ſubſtances as *imponderable*, or without weight.

Beſides the above-mentioned chemical phenomena, relative to water and ice, there is another very important one, which will ſerve as a point of compariſon. We find from theſe phenomena but one *ponderable* ſubſtance, known by the name of *water*, and an imponderable ſubſtance called *fire*. Now when the particles of water are in a *liquid ſtate*, a ſtate produced by their *union* with *fire*, a certain diminution in the quantity of *free fire* will bring them to ſuch a *minimum* of diſtance, and arrangement in poſition, that they will unite in a *determined form*, and quit the *fire* which rendered them liquid: or inverſely, when the particles of water are formed into ice, if the quantity of free fire interpoſed therein be ſufficient to ſeparate them, it then combines with theſe particles, and conſtitutes water; this may be called the *fire of liquifaction.*

Now every attentive philoſopher muſt acknowledge that theſe are great phenomena, brought about by the combination of two ſubſtances, one of which is without *weight*; and that theſe phenomena are probably the general characters of a particular claſs. It is to be regretted that the *ponderable* ſubſtance, which is common both to *water* and *ice*, has not a peculiar and appropriate *name*, for this ſubſtance belongs alſo to aqueous vapours. Mr. de Luc was once inclined to diſtinguiſh it by the term *humor.* You will, I hope, be careful to diſtinguiſh the caſes in which I ſhall ſpeak of water as a ſubſtance modified neither by *fire*, nor by any other ſubſtance. To render you more attentive to this diſtinction, I ſhall ſometimes uſe the word humor.

The foregoing analyſis will enable you more clearly to comprehend the nature of *menſtrua*, a claſs of ſubſtances of which the knowledge is very important. I ſhall confine myſelf to a few inſtances.

The name of *acids* has been given to *liquid* ſubſtances, which ſeem to be nothing more than water joined to certain *imponderable* particles. Thus acid liquors are to be diſtinguiſhed from the acids themſelves.

The general phenomena of *acid liquors* are the *affinities* exerciſed by their particles, as well amongſt themſelves as upon other ſubſtances. But *water* (conſidered here as humor) being united to fire, exerciſes certain affinities, as well in itſelf as upon other ſubſtances: other particles, therefore, as *imponderable* as fire, may produce ſuch changes therein as may alter, in ſome reſpects, it's natural *affinities*; and we are authorized to think that this is the caſe, unleſs the ſuppoſition be contradicted by facts.

To ſee this, let us examine the formation of acid liquids, and alſo their different products. Now when acid liquids are formed, we have every reaſon for ſuppoſing the preſence of *water*, either in the ſolid or liquid ſubſtances employed, or in the *vital* or *atmoſpheric* air, which on decompoſition is joined thereto. Thoſe who adopt the hypotheſis of *M. Lavoiſier* may object to the preſence of water in theſe airs: for in the combuſtion of ſulphur, or phoſphorus, &c. they conſider *vital air* as the *acidifying* principle, and the ſubſtances as *acidifiable* baſes. But this ſuppoſition is neither neceſſary nor natural. It is not neceſſary, becauſe the phenomena may be as well explained without it. If there be a ſufficient quantity of *vital air*, all that we perceive is, the production of an acid liquor; i. e. (according to our opinion) a quantity of water whoſe particles are united to an acid. Now if water is the *ponderable* part of all aeriform fluids, an hypotheſis which is ſufficient to account for every chemical phenomenon, and is the only one that accords with meteorological phenomena; it is eaſy to conceive, that on the decompoſition of *vital* air, a quantity of water united to acid particles may be liberated. For example, we conſider ſulphur as containing an *acid*, *phlogiſton*, *fire*, *water*, and other unknown ingredients, combined together in a *ſolid* form (of which I ſhall treat hereafter): that *vital air* contains *water* and *fire*, which at a certain degree of heat acquire the power of uniting with *phlogiſton*; and thus you perceive, as far as it is poſſible to ſee into nature, why on the decompoſition of theſe two *compounds* by *combuſtion*, a *liquor* reſults, in which the particles of water are united to an *acid*, diſtinguiſhed by the name of the *vitriolic*.

With reſpect to the French hypotheſis, it ſhould ſeem, that every man would conſider himſelf as relieved of a burden, when he found it no longer neceſſary to admit a ſubſtance, which, without being *acid* itſelf, was yet the cauſe of *acidity*. Further, though acids may be ſuppoſed to exiſt, they can only act in *liquids*, or *expanſible fluids*. So that theſe operations, inſtead of furniſhing us with an idea of *acidification*, of which we have no conception, leads us only to conſider theſe acids as liberated, and enabled to act by their union with a liquid.

It may therefore be aſſerted, with confidence, till ſomething more ſolid is produced, that the operations by which acid liquids are formed, conſiſt in liberating water and the acid particles from their preceding combinations; and thus to produce water charged with certain particles to which *no weight* can be aſſigned, and which are only diſcerned by their properties in the ſubſtances containing them. Now as ſoon as the water thus modified receives the *fire of liquifaction*, it's particles being free to follow their tendencies, enter into new combinations, by means of the acid particles from which it has received theſe new faculties. Let us then purſue theſe particles in the exerciſe of their acquired tendencies; and firſt in the phenomena of the *congelation* and *liquifaction* of the liquids they form.

The *water* of *acid liquors* preſerves it's general faculty of exiſting, according to the difference of *temperature*, in a ſolid or liquid form; but it has undergone two changes, one, by which it's *particles* do not abandon the *fire of liquifaction*, but by a greater diminution of *heat*; by the other, when they do abandon it and unite, they aſſume a different arrangement. Here we only perceive different ſpecific characters of the ſame generical modification. The particles of water (humor) whether alone, or whether combined with an acid, can unite with the fire of liquifaction; but in the laſt ſtate they preſerve it in a lower degree of heat; and when they loſe it, inſtead of grouping themſelves like pure water in a form in which their volume is increaſed, they, on the contrary, occupy ſomewhat leſs room.

By the experiments of Mr. M'Nab, at Albany, in Hudſon's-Bay, we find, that ſpirit of nitre undergoes, according to it's degrees of *acidity*, two kinds of congelation, diſtinguiſhed by Mr. Cavendiſh into the aqueous and ſpirituous. In the firſt, the *ice* being produced by the pure water, ſwims above the reſt of the liquid; in the other the liquid itſelf freezes, and the ice thereof falls to the bottom of the part yet liquid. In the laſt phenomenon the point of congelation changes with the degree of acidity, but is far from following the laws thereof.

Mr. Cavendiſh had determined by other experiments, that the true point of congelation cannot be obtained, but by preſerving therein ſome *icicles* of a former congelation. It is thus that the points of congelation in the following table were determined: the degrees of *acidity* of the ſpirit of nitre are expreſſed by the quantity in weight of marble it was able to diſſolve, compared with it's own weight. The thermometer uſed was on the ſcale of Fahrenheit; the correſpondent terms are the reſults of experiments, reduced to a regular ſeries of degrees of *acidity*.

Spirituous Congelation.

Degrees of acidity.		Point of congelation.
0.568	-	—45.5
0.538	-	—30.1
0.508	-	—18.1
0.478	-	—9.4
0.448	-	—4.1
0.418	-	—2.4
0.388	-	—4.2
0.358	-	—9.7
0.328	-	—17.7
0.298	-	—27.7
0.243	-	—44.2

beginning of the aqueous congelation.

Aqueous Congelation.

Degrees of acidity.		Point of congelation.
0.243	-	—44.2
0.210	-	—17.0

From theſe phenomena, analyſed according to Mr. de Luc's theory, it appears, 1ſt, That by a degree of acidity = 568, fire may remain combined with the particles of water (humor) even as low as —45.5 of Fahrenheit. 2dly, That as the degree of acidity is ſucceſſively weakened, the particles of water acquire the faculty of uniting at higher temperatures, and of quitting the fire of *liquifaction*; but this progreſs towards a maximum, which is at a degree of acidity nearly a mean between the two terms of ſpirituous congelation, the acidity is then 418, and at —2.4 the particles of water unite. 3dly, The acidity continuing to be diminiſhed to 298, the particles of water loſe ſucceſſively the power of approaching without ceaſing to be liquid, ſo much ſo, that at this point fire is ready to combine with them at 22.7. 4thly, This loſs of power relative to the particles of water, continues till the *acidity* is reduced to 243, and at this point the fire of liquifaction does not quit them, but at the temperature of —44.2, which very nearly correſponds to what happened at the greateſt acidity 568: but now a new phenomenon takes place; the particles of water being leſs charged with acidity, again tend to cryſtallize in their own way, and thoſe that are moſt favourably diſpoſed thereto, quit their *acid* and the fire of liquifaction, and become common ice. Laſtly, from this point, the more the acidity is diminiſhed, the ſooner the particles of water unite, ſo that when the acidity was only 210, ice (of pure water) was formed at the temperature of 17. Theſe ſingular phenomena are not peculiar to ſpirit of nitre, they have been alſo obſerved in ſpirit of vitriol, as may be perceived by the reſult of experiments formed into a table.

Strength.	Freezing point.
977	+ 1
918	— 26
848	+ 46
846	+ 42
758	— 45

From hence we may conclude, that oil of vitriol has not only a ſtrength of eaſieſt freezing, but even a ſtrength ſuperior to this; it has another point of a contrary flexure, beyond which, if the ſtrength be increaſed, the cold neceſſary to freeze it again begins to diminiſh. From the weakeſt degree of the acid 758, to that of 848, there is an increaſe of 91° in the freezing point. The acidity increaſing to 918, the freezing point falls again 72°, and riſes 27, when the acidity becomes 977.

Now there are in theſe phenomena of *acid liquors* no ſymptoms which ſuffer us to conſider them as ſimple ſubſtances *ponderable* in their nature, nor as compounds of two ſubſtances, the one *acidifiable*, the other *acidifying*, and both *ponderable*. According to the firſt of theſe notions, in which the acids are conſidered as *diſſolved* in water, we find no point at which to ſtop in order to determine their proper weight; in the water they are only perceived by their effects, in other compounds they are not diſcerned: thus, nothing here hinders our conſidering them as *imponderable*, if other circumſtances conduct us to this concluſion. The ſecond notion ſeems to exclude this ſuppoſition, becauſe a known *weight* is attributed to the acidifiable and acidifying particles; but the foregoing experiments deprive this idea of all probability; it cannot explain the extraordinary changes in the *freezing point*, occaſioned in the ſame ponderable ſubſtance, merely by the addition of more or leſs water.

But to be more particular, when the ponderable part of *vital air* is employed as an *acidifying* principle to produce an *acid*, is it a *liquid*, a ſubſtance by it's nature capable of being *frozen* and *liquified?* Here the advocates for this theory leave us in the dark; we call in vain for explanation. If the *ponderable* part of *vital air*, by being joined to the *ponderable* part of *inflammable air*, produces water, can it in the ſame operation, the combuſtion of *ſulphur* for inſtance, produce an *acid?* Here alſo we receive no explanation. If in the combuſtion of ſulphur, part of the *vital air* is uſed to form an *acid*, part with *inflammable air* to produce water, what is the ratio of the two portions? By what means ſhall we diſtinguiſh them? What is the *acidifiable* ſubſtance in *ſulphur*, diſtinct from *inflammable air?* The partizans of the French theory are obdurate, and will afford us no explanation. If, inſtead of this obſcure theory, you conſider the water formed by the two airs to be united to an acid, the whole is readily explained, and the double flexure of the freezing point eaſily underſtood.

From the *cryſtallization* of pure water, we learn, that it's ſimple particles are of a certain form, and that they tend towards each other by certain determined ſides. Now the different combinations of the acid with the particles of water may change the tendency of theſe to collect themſelves together, and occaſion the above deſcribed flexures: how this is effected, might eaſily be ſhewn by geometry, though it cannot be rendered a ſubject for theſe Lectures.

It does not appear that the difference in ſpecific gravity between acid liquors and water is owing to any *ponderable* ſubſtance added to the water; but rather to this, that the particles of water are joined to an imponderable ſubſtance, by whoſe means they may be brought nearer to each other without quitting the fire of liquifaction. Now all the preceding phenomena confirm this theory; for they prove in general, that the particles of acid liquors may be brought much cloſer together than thoſe of water, without loſing the fire of liquifaction; and you will preſently ſee, by a very clear example, that the cauſes which influence the *freezing point*, extend their effect to the general ſtate of liquids. I ſhall firſt, however, mention another phenomenon, which furniſhes a direct proof of the ſuppoſition before us.

If you mix pure water with an acid liquor, the ſpecific gravity of the mixture is greater than the mean of the ſpecific gravities of the ingredients: a clear proof that the acidity cauſes the particles of water to approach, following an increaſing law therein; becauſe the mean approach of the particles is greater than the mean acidity of the united maſſes. This is alſo confirmed by a ſimultaneous effect, that is, the ſudden effect of the preſſure on the free fire of the maſs, which augments the heat thereof; as a bar of iron is heated by forging. The preceding remarks on acid liquors apply ſo naturally to alkaline liquors, that

it

it will be unneceſſary to mention them here. In neither is there any thing which leads us to think, that the difference of acid and alkaline liquors from pure water depends on *ponderable* particles.

From the union of acid and alkaline liquors reſult *ſaline liquids*, from which afterwards by ſimple evaporation we obtain *neutral* ſalts, that is, ſolids of a certain form, which do not receive the fire of liquifaction at the temperature of the atmoſphere, unleſs we reſtore to the ſalt the water that was *evaporated* from it. Now if acid and alkaline liquids are nothing but water modified by certain different particles, their ſolid products ſhould be nothing more than water itſelf, modified by the union of theſe particles; and this the water of cryſtallization directly authorizes us to conclude. Let us then conſider this phenomenon further. In ſome *ſalts*, after the water of cryſtallization is evaporated, the remaining maſs is no longer capable of being liquified without an addition of water; in others, the maſs may be liquified alone, by a great degree of heat. Now here, we only ſee the modifications of the general phenomena of this claſs; namely, different combinations of the particles of water with certain other particles, which changes conſiderably their faculty of receiving the fire of liquifaction; and we even ſee, theſe combinations of water may be ſuch, that it's particles refuſe to receive the fire of liquifaction, in ſome caſes without a great degree of heat; but even abſolutely in other caſes.

If, after *ſalts* have been reduced by evaporation to *a refractory ſtate*, the water which was evaporated be reſtored with a ſmall addition, the molecules of water, which form the ſenſible maſs of the mixture, re-acquire the fire of liquifaction at the temperature of the atmoſphere, and we obtain *ſaline* liquids.

Dr. Blagden, in his paper on congelation, has ſhewn, that all liquids, ſuſceptible of being frozen, would, like water, bear to be cooled ſeveral degrees below the freezing point without congealing. Under the ſame circumſtances acid, alkaline, and ſaline liquors, have the ſame property; a further proof that they are the ſame ſubſtance differently modified.

Saline liquors quit the fire of liquifaction ſooner than pure water; but attended with another circumſtance, ſtill confirming the idea of their being a modification of water. When acid and alkaline liquors freeze, the particles of water therein are ſo arranged as not to occupy a greater ſpace, which you have ſeen was the caſe with pure water; but this property appears again in their *compound* ſaline liquids.

Thus when the particles of acids and alkalies ſeparately modify the molecules of water, the moment that theſe loſe the fire of liquifaction, they are grouped into ſolids, which occupy leſs ſpace than was before occupied by the molecules which compoſe them; but if the particles of water are modified by thoſe of an acid and alkali, they arrange themſelves as if it were pure, but only ſlower, exhibiting only varieties in the modification of the ſame ſubſtance. *Oils* are, probably, nothing more than water modified by imponderable ſubſtances, among which we are to reckon phlogiſton.

There is no phenomenon of acid, alkaline, and ſaline liquids, which can lead us to aſſign a diſcernible weight to any other particles but thoſe of pure water.

In all theſe phenomena we only perceive the developement of an ancient principle of chemiſtry, *that no ſubſtance can act chemically, unleſs it be diſſolved*; for in order that the particles of any ſubſtance may obey it's reſpective *tendencies*, they muſt have liberty to move, and this they can only have in liquids and expanſible fluids. The particles of water, from their faculty of being united with fire, are ſuſceptible of liquidity, and when in this ſtate, can obey either their natural tendencies, or thoſe they may have acquired by combination. It is thus that water becomes the *univerſal menſtruum*; that is, by it alone all other menſtrua exiſt, becauſe it's particles will acquire as many various tendencies, as there are ſpecies of ſubtil particles to unite therewith, either ſeparately or conjointly. Among the changes in tendency, which take place in the particles of water, there is a claſs of great importance in the operations of nature; namely, that which relates to their different aptitude of receiving, and of retaining the fire of liquifaction; from whence, beſides different liquid ſtates, they are capable of aſſuming a great variety in a ſolid form, the ſolidity depending principally on this, that the particles are not capable of being united with the fire of liquifaction, but at a certain temperature, or by the addition of certain ingredients. *Salts* are, hitherto, the only ſolids we have conſidered as produced by water; with reſpect to theſe, *pure water*, whether liquid, or as ice, is a *flux*, by means of which they are fuſible at the temperature of the atmoſphere, nay even at a low temperature; but conducted by analogy, we may proceed further in the abſtract analyſis of ſolids.

When you conſider all the ſolids on the ſurface of our globe, as well organized bodies, as natural foſſils, and examine the certain and uncertain reſults of our analyſes, you will not be able to trace in theſe bodies any ſubſtances *ponderable* in themſelves, but *water* and *elementary earths*, taking the term, elementary earth, in a general ſenſe. Among the ſubſtances, which are not diſcernible by their weight, we have *light*, *fire*, *electricity*, *acids*, *alkalies*, *phlogiſton*, and the peculiar particles of certain airs. Every terreſtrial phenomenon ſeems to announce other imponderable ſubſtances; and from hence you may conceive how many cauſes of this claſs are concealed from us by our ignorance.

Such then are the ſubſtances by which the immediate phyſical cauſes produce the phenomena of our globe; the *ponderable* ſubſtances are water (humor) and earths; the remaining terreſtrial ſubſtances conſiſt only of particles of different claſſes, but of ſuch ſubtilty, that whatever be their quantity in the maſſes that we *weigh*, their *weight* has hitherto eſcaped. Water will unite with all theſe particles, but at different degrees, and acquires by the union different affinities, from whence immediately reſult various liquids, expanſible fluids, and ſome ſolids, which are fuſible at different temperatures of the atmoſphere, either immediately, or with water for their flux. By theſe combinations in different ſtates with the earths, ſolids are produced, on which theſe means of liquifaction have no power. All theſe combinations can only take place in *liquid* water, in which they have an opportunity of exerciſing their affinities: and when ſolids are formed therein, it is in certain caſes, by the addition of ſome ſubſtances, and the ſimultaneous emiſſion of ſome expanſible fluids. Theſe ſolids are no longer ſolvible in the remaining fluid, and in order that it may diſſolve them, they muſt be deprived of their additional ſubſtances, and their expanſible fluids muſt be reſtored to them. Now with reſpect to the greater part of the ſolids of our globe, as well thoſe which were formerly formed on it's ſurface, as thoſe which are daily forming there, theſe combinations are the great ſecret of nature.

The preceding analyſis developes this ancient *principle* of chemiſtry, *that fire is the agent of all diſſolution.* This propoſition is true, but only mediately; for *light* is the firſt agent of every chemical operation. By *light* united to ſome ſubſtance hitherto undetermined, *fire* receives it's exiſtence. By *fire* the particles of water (humor) receive their liquidity, that is, the power of obeying, although contiguous to each other, not only their own tendencies, but thoſe they acquire by the addition of other particles. By theſe additions the particles of water are more or leſs diſpoſed to retain or to receive the fire of liquifaction.

Marine ſalt may be conſidered as a refractory ſolid, and common ice as a fuſible ſolid. Theſe two ſolids being mixed above a certain temperature, have the power of ſeizing in common the fire of liquifaction at all points where they touch. This is the general principle of other fuſions by fluxes. For experiment teaches us, that certain ſolids being mixed can receive the fire of liquifaction, whence the affinities of their ingredients have an opportunity of acting. Experiment has alſo ſhewn, that in order that they may receive more eaſily the fire of liquifaction, or that in their common liquifaction, the ſolids deſigned to be produced may be formed, or even ſeparate themſelves by a difference in ſpecific gravity, they muſt be deprived of certain ingredients. Now here again fire comes in to our aid; by it's agency, and that of atmoſpheric air, certain expanſible fluids are formed, others are abſorbed, and the ſolids thus torrified are ready to go into the furnace, and receive the fire of liquifaction.

ON WATER IN A STATE OF VAPOUR.

Though I have explained in my Lectures on fire the more particular phenomena that take place in the paſſage of water into vapour; I have alſo ſhewn you, that water heated to 212°, when the barometer is 29½, flies off in vapour, and becomes an elaſtic fluid, at leaſt 800 times more rare than air. This elaſtic fluid or ſteam is the moſt powerful agent that can be applied to working of engines, where great mechanical power is required. This ſubject being thereby rendered of the greateſt importance to arts and manufactures, you will not, I hope, think your time miſapplied in reconſidering the nature of this wonderful agent; the more as it will in ſome reſpects be exhibited under a different point of view, and with ſome circumſtances which we did not before attend to.

The quantity of fire neceſſary to turn water into ſteam is immenſely great, as you may eaſily convince yourſelves from the operation of a common ſtill, by obſerving the vaſt heat received by the water in the worm-tub uſed to condenſe the vapour. You may ſtrengthen this idea by conſidering, that if a veſſel of water be placed on a good fire, and that though you increaſe the power of this fire to the higheſt degree capable by human art, yet you cannot raiſe the temperature of the water above the boiling point. Now what can become of the vaſt acceſſion of fire which the water in the veſſel is conſtantly receiving. It goes off with the ſteam raiſed from the water, and may be again obtained from it by condenſing the vapour. If you prevent the ſteam from flying off, as in Papin's digeſter, it will retain the heat it has acquired from the fire; where the confined water will be found ſo hot as even to diſſolve bones, and to produce ſuch effects as I have already deſcribed to you. Yet this fire, when combined with the vapour, is as it were neutralized and rendered with reſpect to external objects quieſcent.

To eſtimate the expanſive force of water reduced into vapour, I know no inſtrument ſo convenient as that of Mr. le Chevalier de Bettancourt.* It conſiſts of a veſſel A placed upon a chafing diſh B, having one opening at top, to which a curved barometer is adapted, and another to which a thermometer is filled, and a third with a cock; theſe are, you ſee, ſo diſpoſed, that when the cock is ſhut there is no communication between the interior ſpace and the exterior air.

When the cock is open, and the water is not heated, the mercury will, of courſe, be at an equal height in each of the branches m, m. If the air be then exhauſted from the large veſſel A, and the cock be ſhut, the mercury will riſe from m to k in one branch, and deſcend from m to k in the other; ſo that the water being ſuppoſed to be at the freezing point, the difference between k and k will be 28 inches.

Let the water be heated rapidly, and you will perceive the firſt ſigns of ebullition by it's ſtriking againſt the veſſel, which it will do with ſo much force as to ſhake the whole apparatus; at the ſame time the mercury in the thermometer will riſe, and that in the barometer will fall; and when the mercury is at the ſame height in each leg of the ſyphon, the thermometer will be at 212°, the preſſure of the ſteam at this temperature being an exact counterballance to the weight of the atmoſphere. If you now increaſe the heat of the water, the mercury will riſe in the branch on which the air preſſes, and deſcend in the other; the difference will depend on the temperature of the water, or increaſed expanſive force of the ſteam. If you add to this difference in the two columns of mercury, the height of the mercury in a common barometer, their ſum will expreſs the height of a column of mercury, repreſenting the expanſive force of the ſteam. The difference in the level muſt be uſed poſitively or negatively, according as the thermometer is above, or under 212.

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* See fig. 11, of pl. 6. vol. i. I have before obſerved, that the Lectures on water were originally deſigned to make a part of the firſt volume.

There is no occaſion for two barometers; if the open end of this was ſealed, it might then be filled like a ſyphon barometer.

With this apparatus Mr. Bettancourt made a variety of experiments, the reſults of which are given in the following table:

TABLE.

Degrees of Reaumur's thermometer.	Expanſive force.
0	0.00
10	0.15
20	0.65
30	1.52
40	2.92
50	5·35
60	9·95
67	14.50
70	16.90
86	28.00
90	46.40
95	57·80
100	71.80
104	84.00
110	98.00

When vapour is expoſed to a great heat, it's bulk, as you have ſeen, is conſiderably augmented; at 212° water is only rarified to 26; but with the ſame degree of heat vapour is expanded to 13 or 14000 times the volume which it occupied as water. Of this you may eaſily aſſure yourſelves, by taking a glaſs tube with a ball at the end thereof 2 inches diameter; let a drop of water paſs into the ball of one line diameter; the ſolidity of theſe two ſpheres will be to each other as 13824 to 1. Heat the ball ſo as to convert the water into vapour, and it will fill the whole ſphere, and force the air out of the ball, as you will find by immerging the end of the tube in water, a little warm, leſt the ſudden application of cold ſhould burſt the ball; and in proportion as the vapour is condenſed by cold, the preſſure of the atmoſphere will force the water into the ball ſo as to fill it entirely; proving thereby that the vapour had forced the air out of it, had aſſumed a bulk near 14000 times larger than it occupied as water.

It is impoſſible to give you an accurate idea of a ſteam-engine without a model. I ſhall therefore content myſelf in this place with laying before you a few of the general principles on which it acts. It has been ſhewn you in the Lectures on air, that the preſſure of the atmoſphere, at a mean, may be eſtimated at 14.8 pounds avoirdupoiſe for every ſquare inch.

If therefore a vacuum be by any means made in a cylinder, which is furniſhed with a moveable piſton, ſuſpended at one end of a lever, or ballance beam, the preſſure of the atmoſphere will preſs down the piſton with a force proportionable to the area of the ſurface, and will raiſe an equal weight at the other end of the beam.

Water, as you have ſeen, may be rarified near 14000 times, and was capable of forming a vacuum by a degree of heat capable of keeping water in a boiling ſtate: by increaſing the heat you have alſo ſeen, that the expanſive force of the ſteam may be rendered much ſtronger. The ſteam may be condenſed or reduced to water by a jet of cold water diſperſed among it, ſo that 14000 cubic inches of ſteam may be reduced into one cubic inch of water only, and thus a vacuum is partly obtained.

Though the preſſure of the atmoſphere be about $14\frac{8}{10}$ pounds upon every ſquare inch, yet on account of the piſton of the ſeveral parts, of the imperfection of the vacuum, the piſton in the common engines does not deſcend with a force exceeding 8 or 9 pounds upon every ſquare inch of it's ſurface. In Mr. Watt's improved engine, are about 12 pounds and a half upon every ſquare inch.

The piſton being preſſed by the atmoſphere with a force proportionable to it's area in inches, multiplied by about 8 or 9 pounds, depreſſes that end of the lever, and raiſes a column of water in the pumps at the other end of the beam equal to that weight. When the ſteam is again admitted, the piſton is forced up by it's expanſive power, and the pump rods ſink; but when the ſteam is condenſed, the piſton deſcends, and the pump rods riſe; and ſo alternately as long as the engine works.

MR. DE LUC'S THOUGHTS ON THE STATE OF AQUEOUS VAPOUR IN THE ATMOSPHERE AND LAWS OF EVAPORATION.

As no perſon has paid ſo much attention to meteorology and the branches of philoſophy relating thereto, as Mr. de Luc, I ſhould not think I had given you an accurate idea of this ſubject without laying before you the reſult of his experiments and obſervations; and I may venture to aſſert, that you will make very little progreſs in this part of philoſophy, unleſs you are maſter of his principles.

Mr. de Luc's notions concerning rain were firſt changed from an obſervation on the *glacier de Buet*, of a degree of *dryneſs* in the *air*, abſolutely unknown in the valley at the ſame temperature. This obſervation, followed by others, led him finally to conclude, "that rain does not proceed from the *moiſture* which exiſted in the atmoſphere prior to the formation of the *rainy clouds*."

By experiments with his hygrometer he has ſhewn, that air may be entirely deprived of the *immediate product of evaporation*; the conſequence of which is *abſolute dryneſs*. The ſame inſtrument ſhews, that this product of evaporation has a *maximum*, variable with the temperature, but *conſtant* under the ſame temperature. The hygrometer is *fixed* by theſe two ſtates of air; no method of *drying* or of moiſtening make it paſs beyond theſe boundaries, which thus become the extremes of a ſcale, referring to a total ceſſation or maximum of moiſture.

In the ſame hands the hygrometer has ſerved to fix our ideas of the cauſe by which water ſimply evaporated in air may be *precipitated*. Theſe cauſes are the ſame with thoſe, which in air, where the quantity of water evaporated does not change, occaſion an augmentation of humidity, the neceſſary forerunner of the precipitation of water. Experience points out two, and only two, the *condenſion* of air, or it's being *cooled*. Some philoſophers have thought that humidity was increaſed by rarifying the air; forming their opinion from thoſe experiments, where the air in a receiver, on being rarified, produced a miſt or fog. Meſſ. Wilcke, Nairne, and de Sauſſure have ſhewn, that if care be taken to exclude from the apparatus every freſh ſource of evaporation, the rarifaction of air promotes *dryneſs*. The phenomena, on which the contrary hypotheſis is founded, ariſe from water left in the apparatus, and the miſt is produced by the acceleration of evaporation in the rarified air, and the inſtantaneous cooling of the ſpace containing the air. The water which evaporates, preſerving ſenſibly the ſame heat which acted on it before, fills the receiver with vapours more denſe than the maximum relative to the momentary diminution of temperature, conſequently they precipitate themſelves ſuddenly. Thus this theory correſponds with the phenomena of the precipitation of water by the rarifaction of air, which is unaccountable on the ſuppoſition of the diſſolution of water by air: for in the latter hypotheſis the particles of water are united by *affinity* to the particles of air. But neither the theory of *affinities*, nor any fact concerning them, authorizes us to believe, that two ſubſtances thus united, ſhould acquire a tendency to ſeparate, becauſe the particles of the mixture were removed to a greater diſtance from each other; a circumſtance, which, as it leſſens their tendency to each other, ought to give them a better opportunity for exerciſing their affinity to water.

Humidity cannot therefore be increaſed by this cauſe, ſince the augmentation of humidity would be a ſign that water was ſeparating itſelf more efficaciouſly from the particles of air. Now in Mr. *de Luc*'s theory, when an aqueous fluid mixed with air produces moiſture therein, this moiſture muſt be diminiſhed by rarifying the air. And this is really the caſe, for there is leſs water in the receiver after a portion of the vapour has been pumped therefrom. The temperature is ſoon alſo re-eſtabliſhed by the fire, which paſſes through the receiver, to ſupply the place of that which was carried away with the vapour.

Rarifying the air, when the quantity of evaporated water remains the ſame, is therefore a cauſe of *dryneſs*, inſtead of *humidity*. Now with reſpect to the other cauſe of an increaſe of moiſture, the *condenſation* of the air, it cannot be ſuppoſed in the atmoſphere; there remains therefore but one cauſe by which we can account for the precipitation of water which is evaporated in open air, namely *cold*; and from time immemorial thoſe who have endeavoured to explain rain by this cauſe, have had recourſe to ſtrata of air in motion, which were more or leſs warm than thoſe they met; but this explanation is alſo chimerical.

When, in a given maſs of air, the evaporated water is at it's maximum in a given temperature; if the heat be increaſed, the particles ſeparate further, and the air will contain more water. If the particles are brought nearer together, the water ſuperabounds, and the exceſs is precipitated. Theſe facts are certain. Now let us ſuppoſe two ſtrata of air of different temperature meeting each other, each of them containing evaporated water at it's maximum for the reſpective temperatures; the warmeſt ſtratum will loſe it's heat, and conſequently it's ſuperabundant water; but the other ſtratum will acquire this heat, and be therefore capable of receiving this ſuperabundant water.

When Mr. de Luc and his brother were at the bottom of the *glacier de Buet in* 1770, it had rained for ſome time, the valley and neighbouring mountains were imbibed with water. There was alſo a very great evaporation from the ground of theſe mountains, which was increaſed by the quantity of melting ice. They however experienced a degree of dryneſs unknown at the ſame temperature upon the plains. Two years after, returning to the ſame place with an hygrometer, they found that the humidity diminiſhed as they roſe, and when they arrived at the ſummit where the ice was beginning to melt, they found that ſame extraordinary dryneſs which had ſo much ſtruck them on their firſt viſit.

While they were upon the glacier, dry as it ſeemed to be, ſome clouds began to form in the ſtratum where they were ſituated; they rolled firſt about the mountain, but they ſoon were formed throughout the whole ſtratum, extending to a great diſtance towards the plains, and increaſing with ſuch rapidity, that Mr. de Luc and his brother thought it prudent to deſcend; the hygrometer ſtill advanced towards dryneſs. Soon after their departure from the *glacier*, it was covered with clouds, and before they had attained their lodging there was a heavy rain from the very ſtratum, which a little before was ſo exceeding *dry*; the rain continued during the whole night, and part of the next day.

Mr. de Sauſſure has confirmed theſe obſervations of Mr. de Luc by many more, which all tend to prove the great dryneſs of the atmoſphere in theſe ſuperior regions.

The water which is at the lower part of the atmoſphere is continually evaporating and riſing in the air, but this evaporation does not increaſe the moiſture therein; for in a dry ſeaſon it goes on diminiſhing, the ground at laſt becomes dry, the vapours diſcontinue, and the dew ceaſes every where but near water. This phenomenon does not however appear ſurprizing to thoſe who imagine, that the evaporated water is collected in the higher regions, where the clouds are formed. But this idea muſt be abandoned, for we now know, *that in ſerene weather, before the clouds are formed, and even among the clouds, the upper regions are at leaſt as dry as the lower part of the atmoſphere, in it's greateſt degree of dryneſs, at the ſame temperature.* Theſe clouds are not therefore formed from the moiſture of the air. The immediate product of evaporation in ſome manner changes it's nature in the atmoſphere; for it does not ſenſibly affect the hygrometer; and it's return to a ſtate of aqueous vapour to produce clouds and rain, proceeds from ſome cauſe of which we are ignorant.

Of the various hypotheſes to reſolve this difficulty, that of Mr. de Luc is the moſt probable, who ſuppoſes, *that the aqueous vapours are turned in the atmoſphere into an aeriform fluid, and that rain proceeds from the decompoſition of this air.* On this hypotheſis it is eaſy to perceive why the hygrometer is not affected by the quantity of water that is often exiſting in the atmoſphere.

The difference between *water* as *vapour*, and as an *aeriform* fluid, conſiſts in this; that in vapour the union of water with fire is very weak, and is eaſily deſtroyed by *preſſure* or *cold*; but by the addition of another ſubſtance it loſes theſe properties, and becomes an *aeriform* fluid. There are many reaſons for ſuppoſing that a variety of aeriform fluids are included in the atmoſphere, which by reſiſting the operations uſed to diminiſh the atmoſphere are unknown to us. Now the operation of theſe, or of other ſubſtances in the air, may decompoſe water conſidered as an aeriform fluid, and thus occaſion rain.*

The variations of the barometer ſeem naturally to lead us to ſome ſuch concluſion; for when the barometer falls as a ſign of rain, it is from a change in the ſpecific gravity of the air; but Meſſrs. de Luc and de Sauſſure have proved, that there never is a ſufficient quantity of vapour in the atmoſphere to occaſion the difference produced by this inſtrument. There are many other phenomena which are not accountable on the uſual principles, and conduct us to look for ſome further change in the theory of the atmoſphere.

LAWS OF EVAPORATION BY M. DE LUC.

M. de Luc here, as before, conſiders moiſture in the air, as the modification of a particular fluid, conſiſting of water and fire, mixed with the air, but *independent* thereof.

He alſo conſiders evaporation (which occaſions this moiſture) as an operation of fire without the interference of air.

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* The reader muſt be referred to M. de Luc's Letters, to learn why the French theory of the decompoſition of water does not apply to this caſe.

That it is an operation of fire, is plain; for every liquor cools when it evaporates, becauſe the portion of the fluid that diſappears, carries away a quantity of fire from the liquor.

Mr. Watt has ſhewn, that in the ordinary evaporation of water in open air, the quantity of heat loſt by the maſs, bears to the quantity of water carried away, a greater proportion than that which is found in the ſteam produced by boiling water. There is, therefore, no room to doubt that ſteam is formed in the firſt as in the laſt caſe.

Whenever water is in a ſtate of evaporation; an expanſible fluid, compoſed of water and fire, is produced. To this fluid M. de Luc gives the name of ſteam. I uſe this and vapour indifferently.

As long as ſteam exiſts, it exerts a power of preſſure like air itſelf; but it does not belong to the claſs of permanent elaſtic fluids; as it may be decompoſed either by preſſure or by cooling.

There is, as you have ſeen, a material difference between what are called *permanently elaſtic fluids* and *ſteam*, or the *vapour* of water; the former will undergo every known degree of atmoſpheric preſſure without being decompoſed; but vapour is decompoſed by too great a preſſure. The particles of the water being hereby brought nearer together unite, and quit the fire, which in paſſing from them manifeſts it's uſual properties.

Permanently elaſtic fluids cannot be decompoſed in veſſels hermetically ſealed, becauſe they are thereby prevented from receiving the action of the bodies with which they have a greater affinity than with thoſe which ſupport them in an aeriform ſtate; but *ſteam or watery vapours* may be decompoſed in veſſels hermetically ſealed, from the tendency of the fire with which it is united to an equilibrium; thus, when the exterior heat diminiſhes, the fire quits the water to re-eſtabliſh the equilibrium of temperature. If the fire becomes ſufficiently abundant on the outſide, it re-enters the veſſel, and vapours are again formed.

As the expanſive property of vapour depends, every other circumſtance being the ſame, on fire, it is greater in proportion as the particles contain a greater quantity.

It appears, that ſteam is decompoſed either by preſſure or by cooling; becauſe at a given temperature it has a certain fixed maximum of denſity, which increaſes with the temperature.

Thus, when the fluid is arrived at the maximum correſpondent to a certain temperature, it will be decompoſed, either by being cooled, it's maximum being too great for this temperature, or it will be decompoſed by an increaſe of preſſure without any change of temperature; for here it's denſity is too great for that temperature: in either caſe the water is ſeparated from the fire, which ſupported it as ſteam.

The degree of preſſure, or expanſive force, exerciſed by ſteam, or which it can ſupport without decompoſition, depends on temperature, and is proportional to it's denſity.

Steam is formed at every temperature where a previous ſpace permits it's expanſion; but no ſteam can be formed where it has to overcome an obſtacle ſuperior to it's expanſive power at that degree of temperature; and if it be formed, becauſe the obſtacle, or preſſure, did not exceed it's power, yet if the preſſure increaſes, or the temperature lowers ever ſo little, it is totally decompoſed.

It is theſe circumſtances that determine both the degree of heat at which water begins to boil, and the variations of that degree, according to the variations of preſſure; for *ebullition* is that ſtate of a liquid in which ſteam is continually formed within in itſelf, notwithſtanding the external preſſure; and to produce this expanſive power in ſteam, a certain degree of heat is neceſſary in the fluid, which is determined by the degree of preſſure. As for the fixity of the degree of boiling water under a conſtant preſſure; it is produced by the equilibrium between the quantity of fire, which continues to penetrate the water, and that which goes off in ſteam; the differences which may happen in the quantity of fire that penetrates the water, having no other ſenſible effect than that of producing a more or leſs rapid formation of ſteam.

From hence we may perceive the difference between the phenomena of common *evaporation* and *ebullition*. Ebullition requires a determined degree of heat, becauſe the ſteam cannot be formed within the water, unleſs it is ſufficiently ſtrong to overcome the actual preſſure on the water: but in common evaporation the ſteam and vapour is formed at the ſurface of the water by every degree of temperature; for it meets with no reſiſtance, but what it can always overcome; it mixes only with the air, and this it expands in proportion to it's quantity, in the ſame manner as if it were a new quantity of air.

The ſteam, formed by common evaporation, is of the ſame nature with that of boiling water; but with reſpect to the preſſure it undergoes, it is ſimilar to that produced by evaporation under an exhauſted receiver. Under the exhauſted receiver, the reſiſtance the ſteam meets with is from itſelf, and is, conſequently, proportional to it's own expanſive power. In open air, the part of the whole preſſure incumbent on the ſteam is to that whole, as it's power is to that of the whole maſs, the reſt of the preſſure being ſupported by the air with which it is mixed; which proportion in the preſſure ſteam undergoes, brings it exactly to that of the firſt, as is proved by experiment.

When the thermometer is at 65°, the maximum of evaporation in an exhauſted receiver,[*] ſupports 0.5 inch of mercury in the ſhort barometer gage. That the evaporation in vacuum has the ſame cauſe as in open air, is clear from the loſs of heat by the liquid in this caſe, as well as the other: an equal preſſure is alſo produced, and added to that of the air, when the receiver is filled with air, as will appear by the following example:

If the thermometer be ſtill about 95, and the receiver be filled with air of the ſame denſity as that in the room, a barometer placed in that receiver, will ſtand at the ſame height as in the open air. If a ſufficient quantity of water be introduced for producing the maximum of evaporation, the incloſed barometer, like the gage, will riſe 0.5 of an inch.

Now as the barometer is, in every caſe, a manometer, the phenomena, obſerved in cloſe veſſels, give us a true idea of what happens to ſteam in the atmoſphere. When ſteam is mixed with air, be the maſs ſhut up in a veſſel, or be it in a certain part of the atmoſphere, diſtinct by it's place, both fluids will act on the barometer, or on every obſtacle, and thus againſt each other, according to their reſpective power; becauſe no mechanical cauſe can produce the decompoſition of ſteam, but by forcing it's particles to come nearer each other, than is conſiſtent with the temperature by which they are ſupported; which caſe cannot happen in the atmoſphere, except by the accumulation of ſteam in ſome part of it; ſince elſewhere it only remains mixed with the air, according to it's own laws, as if there were no air.

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[*] The mean reſults of experiments.

Mr. de Luc conſiders the whole theory of hygrology a ſcience, whoſe objects are, in general, the cauſe of evaporation, and the modifications of evaporated water, as comprehended in the foregoing propoſitions.

The common ſource of the water thus diſſeminated in the atmoſphere, is the ſurface of the earth; whence in ſpontaneous evaporation, both in air, and *in vacuo*, as well as in ebullition, we ſee water carrying off latent fire.

If the product be collected in a cloſe ſpace, it acts in the ſame manner as a new quantity of expanſive fluid.

It is known, by experience, that an expanſive fluid is really produced by ebullition, and by evaporation in an exhauſted receiver; and no good reaſon can be aſſigned to ſhew why the cauſe of evaporation, and it's product, ſhould change in any caſe only by the preſence of air; and on examining what may happen in open air, we find no particular cauſe of the deſtruction of that expanſible fluid, or any difficulty in conceiving it's diſſemination in every part of the atmoſphere.

Here we loſe ſight of ſteam; for watery vapours are not diſcernible of themſelves, and it is on this account they are not perceived in the atmoſphere. Mixed therewith, they are not to be diſtinguiſhed from it, becauſe they are as tranſparent as itſelf. In a vacuum they would be taken for an elaſtic fluid, if we judged of them only by their mechanical effects, without ſubjecting them to a chemical analyſis. In the air their mechanical action is as little perceivable as that of any ſcattered particles of air; and we ſhould be ignorant of their function in the atmoſphere, if it were not for their property of producing moiſture.*

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* See Mr. de Luc's paper in the ſecond part of the Philoſophical Tranſactions for 1792.

OF VESICULAR AND CONCRETE VAPOUR.

When vapour or ſteam is decompoſed, if it be contiguous to ſubſtances, whoſe heat is leſs than it's own, the fire quits the vapour, and the water is depoſited on the ſurface of the body in the form of dew, and in drops. When the heat is as low as congelation, the vapours are cryſtallized, and depoſited in regular and curious forms.

If there are no ſubſtances contiguous to the vapours in the air, the particles of water unite, and form either ſpherical ſolid drops, hollow ſpheres, or congealed icicles.

The ſolid drops unite and form rain. The icicles are the firſt elements of ſnow; but as they are often very minute, and remain ſuſpended in the air, where they produce different meteors, Mr. de Sauſſure ranks them in the claſs of vapour, and gives them the name of *concrete vapour.*

The exiſtence of the hollow ſpheres, or veſicular vapours, has been often ſuppoſed, before philoſophers were able to exhibit them to the ſenſes. The ſimpleſt and moſt inſtructive manner of obſerving them, is to expoſe a cup of ſome warm aqueous fluid, of a dark colour, as coffee, or water mixed with ink, to the rays of the ſun in a fine day, when the air is very calm; a cloud will riſe from the fluid to a certain height, and then diſappear. An attentive eye will ſoon diſcover that this cloud conſiſts of ſmall round grains, of a whitiſh colour, and detached one from the other. To acquire a more diſtinct idea of their form, you may obſerve them as they riſe from the ſurface of the liquor, with a lens of about one inch and half focus; being careful, however, to keep the lens out of the vapours, that they may not deprive it of it's tranſparency.

You may thus obſerve ſpherical balls of different ſizes proceeding from the ſurface with more or leſs rapidity. The more delicate riſe with rapidity, and ſoon traverſe the field of the lens; the larger fall back into the cup, and without mixing with the fluid, roll upon it's ſurface like a light powder, which obeys every impulſe of the air, and are blown from one edge of the cup to the other, even when there is no apparent agitation in the air. Theſe globules may be ſeen on a ſudden to begin to move, the ſmalleſt riſing by an agitation of the air imperceptible to our ſenſes, flying off and diſappearing, whilſt the largeſt remain rolling on the ſurface without quitting it; at other times you ſee ſome of them, which were ſuſpended in the air, deſcend to the ſurface, and there reel a while like pigeons on a ground freſh ſown, then on the ſmalleſt agitation riſe again, and fly away.

The lightneſs of theſe ſmall ſpheres, their whiteneſs, &c. gives them an appearance altogether different from ſolid globules; their perfect reſemblance to the larger balls that are ſeen floating on the ſurface of the liquid can leave no doubt of their nature; it is ſufficient to ſee them to be convinced that they are hollow bubbles, like thoſe blown from water and ſoap.

Mr. Kratzenſtein endeavoured to eſtimate their ſize, by comparing them with an hair, and found they were 12 times ſmaller than the hair, whoſe diameter was the 300th part of an inch, and conſequently one of theſe was only the 3600th part of the ſame meaſure.

To obſerve them more readily, Mr. de Sauſſure uſed a kind of colipile, formed of two balls, i. e. a glaſs tube ſealed at A, *fig.* 10, *pl.* 5, vol. i. open at D; the two balls communicating with each other, and the opening or neck D. He let

ſome

ſome drops of water paſs into the ball B, and placed it over the flame of a ſpirit of wine lamp; ſpirit of wine was uſed that the balls might not be obſcured; as ſoon as the water is ſenſibly heated in the ball B (the ball C being yet cold), you may ſee the vapours from the ball B enter into the ball C, and there condenſe themſelves in the form of a cloud, which is entirely compoſed of theſe veſicles; but when the water boils in B, the torrent of elaſtic vapours that enter C warms this ball, and the vapour being no longer condenſed, neither cloud nor veſicles are ſeen; it becomes perfectly tranſparent, and the jet proceeds from the neck B, as from an eolipile. If you then remove the eolipile from the flame, and cool, by means of cold water, the ball C, the veſicular vapours will again appear: by placing this ball on the ſtage of a microſcope, you may obſerve theſe vapours with the greateſt convenience.

You may even, ſometimes, be able to obſerve them in a fog, or in a cloud when on a hill: to this end Mr. de Sauſſure uſed a lens of one and a half or two inches focus, which he held near his eye with one hand; in the other he held any ſmooth, flat, and poliſhed ſurface of a black colour, as the bottom of a tortoiſeſhell box; bringing this towards the lens, till it was very near the focal diſtance thereof, he then waited till the agitation in the air brought ſome particles of the cloud into the focus of the lens; when the cloud was thick, this ſoon happened, and he perceived round and white particles paſſing with the rapidity of lightning, others moving ſlowly, ſome rolling upon the ſurface of the tortoiſeſhell, others ſtriking againſt it obliquely, and rebounding like a ball from a wall, others fixing themſelves thereto. Small drops of water might alſo be perceived to ſettle on the tortoiſeſhell; but they were eaſily diſtinguiſhed from the hollow ſpherules, by their tranſparency, their gravity, and their pace.

Further, clouds do not form a rainbow; it is produced by ſolid drops; when a cloud is not in an actual ſtate of reſolution, it does not change the form of the ſtars that are ſeen through it; for infinitely thin meniſcuſſes do not ſenſibly change the courſe of the rays of light. But as ſoon as the cloud begins to reſolve itſelf in ſolid drops; even without clouds, when ſolid drops begin to be formed in the air, the ſtars ſeen through them are ill defined, ſurrounded with a diffuſe light, circles, and halos; hence theſe meteors are the forerunners of rain, for rain is nothing more than theſe drops augmented or united. When the veſicular vapours are condenſed by cold, the water which formed the bubble cryſtalliſes, ſometimes into hoar froſt, ſometimes into ſnow; when it does not freeze, they unite in dew, or deſcend in rain. Many other curious properties concerning the veſicular and concrete vapours are related in Mr. de Sauſſure's excellent Eſſai ſur l'Hygrometrie.

OF MINERAL WATERS.

A full inveſtigation of the properties of mineral waters is the ſubject of chemiſtry; but ſince the diſcoveries of Dr. Prieſtley it has ſo much analogy with philoſophy, that I cannot paſs it over entirely in ſilence.

The name of mineral water is in general given to any water which is found to be ſo loaded with foreign principles as to produce a different effect on the human body from that which is produced by the waters commonly uſed for drink. Our anceſtors were particularly attentive to procure wholeſome water; it was this that determined where they would unite together, and regulated their choice of the ſituation of houſes. *Hippocrates*, the father of medicine, was well acquainted with the influence of water upon the human frame, and affirms that the mere quality of the uſual drink is capable of modifying and producing a difference among men.

When we conſider that many of the ancient philoſophers ſuppoſed that all things were originally derived from water, it is evident they muſt have had an extenſive view of the operations of nature. We ſee that it produces dew, clouds, rain, ſnow, and other meteors; nor can we help obſerving how every vegetable, and every animal, riſes out of it. When we chemically examine the materials of which animal and vegetable ſubſtances are compoſed, we find water to be a principal ingredient. Nothing then remains but the ſolid and inanimate parts of the globe; the various earths, rocks, ſtones, and minerals, of which the dry land and vaſt maſs of mountains are compoſed, even theſe, the more we examine them the more we have reaſon to think, derive their origin from water.

In marble, chalk, and limeſtone, we find evident traces of the ſea; we cannot rationally think otherwiſe of theſe ſtrata, than that water has been greatly concerned in their origin. And further, as we find theſe ſtrata irregularly mixed with the hardeſt rocks both above and below, we muſt conſider them as ſpringing from the ſame ſource. On examining the rocky ſtrata, you will find marks which plainly point out that they originate from the *ſea*. Thus the ſtrata of freeſtone which are very extenſive, evidently ſhew from their appearance that they were originally ſea-ſand; they are divided into ſmall ſtrata, and are diſtinguiſhed into horizontal layers, and have the ſame undulated ſurface as the ſand of the ſea-ſhore.

Flinty ſubſtances ſeem to form the ſtrongeſt objections to this ſyſtem, as they reſiſt the action of water as much as any ſubſtances in nature: but there are many phenomena in nature which ſhew that calcareous earth is convertible by length of time into a flinty matter; and marine ſhells are not unfrequently met with which have loſt their calcareous nature, and are converted into the hardeſt and pureſt flint. In bitumen and coals we find evident traces of a vegetable origin.

The analyſis of water is not only uſeful in a phyſical point of view, but alſo as an object of medicine, in order to determine whether any water is uſeful, to know thoſe which poſſeſs medicinal virtues, and apply them to the uſes to which they are ſuited; or to appropriate to different works and manufactories the waters beſt calculated for their reſpective purpoſes, to correct impure waters, and laſtly to *imitate the known mineral waters* at all places, and at all times. Whether you conſider mineral waters with reſpect to their formation, or the benefit which accrues from them, we have reaſon to eſtimate them as precious gifts of *Divine Providence.* But it is with theſe as with many other bleſſings, we are too often heedleſs and ungrateful. "How many, for whom the wonders of creation, providence, and redemption, have been wrought, that think them not worthy their attention! Angels admire and adore, where man will not deign to caſt an eye, or employ a thought."

The mineral waters are divided into different heads, according to the ſubſtances they contain:

1. The *acidulous,* which contain an aeriform fluid, which gives theſe waters a briſkneſs like that of a fermenting. This briſkneſs is moſt apparent

when the water is poured from one veſſel to another; it is ſometimes ſo conſiderable as to burſt the bottle. They redden the tincture of turnſole, and precipitate lime-water.

2. An acid is ſometimes found in the waters of ſprings, giving them a very ſenſible acidity; this generally ariſes from the vitriolic acid: this acid has, however, in general, ſo ſtrong a diſpoſition to unite with the various ſubſtances through which the water of a ſpring paſſes, that it is ſeldom found in a ſeparate ſtate in the water.

3. An alkaline ſalt is ſometimes met with in water; this is in general the foſſil alkali.

4. Neutral ſalts. Of theſe, thoſe that are moſt generally found are common ſalt, and ſometimes nitre.

5. Earthy ſubſtances. Of theſe the calcareous is ſometimes found. There are mineral waters which contain ſo much calcareous earth, as to become petrifying to other bodies.

6. Earthy compounds. Thus you may often find calcareous and other earths ſuſpended in water by means of an acid. Thus gypſum is contained in almoſt all waters, Epſom ſalt is found in great quantities, and allum is ſometimes to be met with.

7. Sulphureous waters. Theſe waters have been long conſidered as holding ſulphur in ſolution; but Bergman has proved that moſt of theſe waters are more impregnated with hepatic gas: this claſs is known by emitting the ſmell of rotten eggs.

8. Martial waters. Theſe have a very aſtringent taſte, and exhibit a blue colour by the ſolution of precipitate of lime. The iron is held in ſolution either by fixed air, or the vitriolic acid.

Sometimes the acid is in exceſs, and the waters have a penetrating ſub-acid taſte, as Pyrmont and Spa water.

Sometimes the acid is not in exceſs, and the waters are not acidulous.

In chemical writers you will find the method of analyſing theſe different waters. When the analyſis is well made, the ſyntheſis is no longer difficult. And the imitation of mineral waters is now no inſoluble problem. The proceſſes of nature are inimitable only in thoſe operations that are vital. In this inſtance we can do more than imitate, we can vary at pleaſure the nature and proportion of the conſtituent parts, and give them, as circumſtances require, more or leſs energy. In artificial waters the ingredients are known, while the ingredients of waters in their natural ſtate are always unknown.

That which Dr. Johnſon has obſerved of a poet is equally applicable to a philoſopher. To him nothing can be uſeleſs. Whatever is beautiful, and whatever is dreadful, ſhould be familiar to his mind; he ſhould be converſant with all that is awfully vaſt, or elegantly little. The plants of the garden, the animals of the wood, the minerals of the earth, and the meteors of the ſky, ſhould all concur to enrich his mind. By him no kind of knowledge ſhould be overlooked, he ſhould range mountains and deſerts, explore every tree of the foreſt and flower of the valley, the crags of the rock, the mazes of the ſtream, and the great wide ſea, with it's unnumbered inhabitants; he will find them all

—ſpeak their Maker as they can,
But want and aſk the tongue of man:

calling upon him to praiſe his redeeming GOD, who in the intellectual, as in the material world, is LORD and KING; who is obeyed by the angels in heaven, ſerved by the church upon earth, and feared by the ſpirits impriſoned in deep places beneath.

Look at every thing in nature; look at all the variety of creatures therein; conſider it in all it's height and depth, in all it's variety of operations; and you will find it is only for this end, that it may in it's infinite variety of degrees and capacities manifeſt the hidden riches, the inviſible powers, and glories of the ſpiritual world; and be as ſo many ſounds and voices, preachers and trumpets, giving glory, praiſe, and thankſgiving to the GOD OF LOVE.

The preſent Lecture has afforded you freſh inſtances of the wonders and variety, the harmony and magnificence diſcoverable in the works of GOD. There is not, for inſtance, in nature a more auguſt and ſtriking object than the *ocean*. It's inhabitants are as numerous as thoſe on land; nor is the wiſdom and the power of the Creator leſs diſplayed in their formation and preſervation, from the ſmalleſt fiſh that ſwims to the leviathan himſelf. Nor is there any image which gives us a grander idea of the power and greatneſs of God, who hath this raging element ſo much under his command: hence he is repreſented in holy writ as holding it in *the hollow of his hand.*

There the creatures of God multiply in a much greater proportion than by land, and are maintained without the coſt or attendance of man; they are a ſingular flock, which have no ſhepherd but the CREATOR himſelf, who conducts them at different ſeaſons in innumerable ſhoals to ſupply the world with nouriſhment.

By means of navigation Providence hath opened a communication between the moſt diſtant parts of the globe; the largeſt ſolid bodies are wafted with incredible ſwiftneſs upon *one fluid* by the *impulſe* of another, and ſeas join the countries which they appear to divide.

The waters of the ſea are not only prevented from deſtroying the earth, but by a wonderful machinery are rendered the means of preſerving every living thing which moveth thereon. Partly aſcending from the great deep through the ſtrata of the earth, partly exhaled in vapour from the ſurface of the ocean into the air, and from thence falling in rain, eſpecially on the tops and ſides of mountains, where they break forth in freſh water ſprings, having left their ſalts behind them; they trickle through the valleys, receiving new ſupplies as they go; they become large rivers, and after watering by their innumerable turnings and windings immenſe tracts of country, they return to the place from whence they came. The fertility of the earth is owing to GOD, "*who watereth the hills from his chambers.*" Hence all the glory and beauty of the vegetable world; hence the graſs that nouriſheth the cattle, that they may nouriſh the human race; hence the green herb for food and medicine; hence fields covered with corn for the ſupport of life; hence vine and olive trees laden with fruits, whoſe juices exhilarate the heart, and brighten the countenance.

They who in old times paid their devotions to the elements, imagined thoſe elements to be capable of giving or withholding rain at pleaſure. Therefore, we find, the prophet *Jeremiah* reclaiming that power to JEHOVAH, as the GOD who made and governed the world. "Are there any among the vanities of the gentiles that can cauſe rain? Or can the heavens give ſhowers? Art not thou he, O JEHOVAH, our GOD? Therefore we will wait upon thee: for thou haſt made all theſe things." Among the Greeks and Romans, we meet with a Jupiter poſſeſſed of the thunder and the lightning, and an Æolus ruling over the winds; but divine revelation teaches us to reſtore the celeſtial artillery to it's rightful owner. JEHOVAH, the GOD of Iſrael, the CREATOR of the univerſe, the REDEEMER of mankind, contrived the wonderful machinery of light and air, by which vapours are raiſed from the earth, compacted into clouds, and diſtilled into rain. At his command the winds are ſuddenly in motion, and ſuddenly at reſt again. We hear the ſound, but cannot tell whence they come, or whither they go.*

Be particularly careful then that you never term any effect *natural*, with the intention to deny thereby that it is *divine*, or to exclude GOD entirely out of it; for the GREAT ARCHITECT neceſſarily preſides over and directs every wheel of his machine. It is HE that clothes the graſs of the field, and ſendeth the ſpring into the rivers. It is HE that gives corn, and wine, and oil. It is HE alſo that ſends famine, ſword, and peſtilence. One time an epidemic diſtemper raged; 2 Sam. xxiv. 17; and that we might not hereafter on ſuch occaſions *look alone to the noxious qualities in the air*, &c. the *veil* was for once drawn aſide, and preſented to open view the deſtroying angel of the Moſt High.

Nor let the pert reaſoner flatter himſelf that this is a ſyſtem only for thoſe who believe the bible. It is impoſſible to conceive any religion at all, even excluſive of revelation; that is, in other words, to conceive any *truſt*, *reſignation*, *repentance*, or *gratitude*, towards the Deity, adapted to the ſucceſſive ſcenes of human life, upon any other foundation. No independence can be aſcribed to the creature; even the ſun, the moſt glorious inſtrument of created power, viſible in the univerſe, from his firſt glorious appearance to this good day, never ſhed one ray of light by any intrinſic power, or inherent virtue of his own.

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* Dr. Horne, biſhop of Norwich, on the Pſalms.

The *ſource* of *life*, *beauty*, and *perfection*, is too often unperceived by the mere naturaliſt. But he, whoſe eye is opened and illuminated by truth, ſees, contemplates, and adores the AUTHOR AND UNIVERSAL PRINCIPLE OF LIFE; and finds HIM perpetually manifeſting HIMSELF in every object of nature, according to it's capacity or aptitude to receive HIS enlivening beams. Separated from *his life-giving energy*, the whole creation of beings, material as well as intellectual, muſt remain in a ſtate of death. Nought but HIS animating breath can call them forth into life, and array them with robes of beauty.

LECTURE XIV.

ON THE METHOD OF REASONING IN NATURAL PHILOSOPHY.

IN the propoſals for theſe Lectures, I engaged to point out to you the true method of reaſoning in philoſophy, that you might be enabled to diſtinguiſh what is ſound and ſolid therein, from what is hollow and vain. This cannot, I think, be done more effectually than by introducing you to the writings of LORD BACON, whoſe plan for the improvement of knowledge comprehends the whole compaſs of nature. He may be conſidered as the great reſtorer of true learning, and the founder of *experimental philoſophy*; having done more towards detecting the ſources of former errors and prejudices, and towards eſtabliſhing a true method of philoſophiſing, than was effected by all the philoſophers of the preceding ages.

He has given us an *organum* of a different origin and conſtruction from that of *Ariſtotle*; one which, inſtead of *puzzling* all learning with artificial forms, and *perplexing* all knowledge with diſputation, puts *truth* and *nature* to the torture by a thouſand trials, and forces them to confeſs thoſe ſecrets, which in ſpite of *ſyllogiſm* had hitherto lain concealed, and by the diſcovery of which arts and ſciences have been advanced, to the great honour of learning and advantage of ſociety.

Two circumſtances add greatly to the merit of LORD BACON. The firſt is, that at the time his work was written, the world had ſeen no model of inductive reaſoning, from which it's rules might be deduced with amplitude and preciſion. *Poets* and *orators* had brought their arts to perfection, ere they were deſcribed by *Ariſtotle*; his rules were drawn from the moſt perfect models of thoſe arts that have yet appeared: but the *art of interpreting nature* was yet in embryo, when *Bacon* with uncommon energy of mind delineated it's manly features and proportions. The ſecond circumſtance which does our noble author peculiar honour, is, that he was free from every view of founding a ſect in philoſophy, or aiming to procure followers: he was animated with better proſpects, and more diſtintereſted views. He deſired only to lead mankind as it were by the hand, and to inſtruct them ſo to follow nature, as to be under no neceſſity of following any philoſopher whatſoever.

The picture of a true philoſopher cannot be better drawn than by Bacon's own pencil, and in his own example. You find in him a love of ſcience, it's intereſt and advancement, yet without affecting the pomp of learning; he is a free, impartial, and honeſt cenſor of paſt times, yet without haughtineſs or pride; his judgment is correct and ſolid; his wit, though lively and ſublime, never gives into a wild and profane licence, or rude inſult upon ſacred things. His imagination was fruitful and extenſive, ranging at large through all the times and regions of the univerſe, ſuggeſting new thoughts and ideas, and ſupplying him with images to expreſs and embody thoſe ideas. In him, with the utmoſt logical preciſion, you have the ſublimeſt eloquence; and you find him in his "ADVANCEMENT OF LEARNING," triumphing over the barbariſm of the preceding ages, and over the pedantry of that in which he lived. His knowledge was ſo comprehenſive and univerſal, that he ſeems to have been the profeſſor of every ſcience, not only acquainted and familiar with all ages, but admitted as a miniſter into the inſpection and myſteries of all nature. Amidſt this maſs of acquired wealth, the ſtrength and ſplendor of his own ſtock, ſhining forth unimpaired and unrivalled, lending a luſtre to the authority he produces, his depth, his ſtrength, his dignity, and majeſty, ſet him up above every lettered name.

With a capacity of more than ordinary ſize, a giant in the intellectual world, he breaks through the chains with which authority or tradition had fettered the human mind, ſubdues the errors formed and foſtered by ſuperſtition and ignorance, paſſes the columns fixed as the boundaries of human knowledge, and opens new tracts of light and regions of truth, that were before thought incapable of culture or profit; intent as it were upon nothing but truth, or in his own noble language, " vanquiſhed with the immortal love of truth." While he detects and proſcribes vulgar errors, he commits no outrage upon the ancient occupiers, nor offers any groſs inſult upon the common ſentiments of mankind. Nor have we, ſays he, ſet off ourſelves with glory to draw a majeſty upon our inventions, either by triumphs of confutation, or depoſitions of antiquity, an uſurpation of authority, or the veil of obſcurity. Thus with a ſuperiority without the pride of genius, we need not wonder, that, humble as the humbleſt child of faith, he diſavows whatever does impair or intrench upon ſacred truth, and addreſſes the LORD for aſſiſtance and illumination in his arduous undertaking.*

The end of natural philoſophy is to increaſe either the knowledge or power of man, and enable him to underſtand the ways and procedure of nature. By diſcovering the laws of nature, he acquires knowledge, and obtains power; for when theſe laws are diſcovered, he can uſe them as rules of practice, to equal, ſubdue, or even excel nature by art. Upon the diſcovery of theſe laws, depends the perfection of philoſophy, and the enlargement of human knowledge and power.

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* Hunter's Sketch of Lord Bolingbroke.

For this great end *Lord Bacon* exhibits a more perfect method of employing the rational faculty than mankind had been accuſtomed to; and ſhews them in what manner they may exalt and improve the underſtanding, conquer the difficulties, and remove the obſcurities of nature. The firſt part of his NOVUM ORGANUM, which may be called *a grammar of the language of nature*, is deſigned to prepare and purify the mind, that it may be fit to receive the inſtructions, and uſe the inſtruments laid down in the ſecond part.

The human mind, like a mirror, muſt be ſmoothed and poliſhed, freed from falſe imaginations and perverted notions, before it is fit to receive and reflect the *light of truth*, and juſt information. You may therefore, with the Pythagoreans, lay it down as a maxim, that human advancements ſhould be preceded by, or accompanied with, a ſuitable degree of purification; for as the diſeaſed eye endures not, till it be reſtored to health, the view of bright objects, ſo neither can the mind, without due purification, ſteadily contemplate the beauty and ſplendor of truth.

We muſt therefore, in the purſuit of truth, diveſt ourſelves of all the IDOLS or falſe notions that poſſeſs the mind. To every *bias* of the underſtanding, by which a man may be miſled in judging, or be drawn into error, *Lord Bacon* gives the name of *idol*; a word that juſtly characteriſes falſe ſcience; for erroneous knowledge is a ſpecies of idolatry, a worſhip paid to falſe gods, which is only due to the true one.

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All falſehood is oppoſite to truth. Error is that falſehood, which availing itſelf either of the weakneſs of the *underſtanding*, the depravity of the *will*, or the undue influence of the *imagination*, aſſumes the *appearance* of truth. Truth is the health, error the diſorder of the mind. By purifying the mind from error, you will become a fit receptacle for *divine truth*; by purifying your hearts, you will be conjoined to *divine goodneſs*, and will enjoy the happineſs reſulting from ſo exalted a conjunction.

The *idols* of the mind are either acquired or natural, proceeding from the doctrines and opinions of men, the perverted and corrupt laws and methods of demonſtration, or elſe are inherent in the very conſtitution of the mind itſelf. Your firſt labour ſhould therefore be to liberate the mind from falſe theories; the next ſhould be to releaſe it from the ſlavery of perverted demonſtrations; and the laſt to put a check upon it's own ſeductive powers, and either pluck out the inherent idols, or ſo to watch over them that the depravities they occaſion may be corrected. It is a long time before we can be brought to ſee any thing amiſs in the way we have been uſed to; and even when we do, it is not eaſy to change what is wrong. Where there is a chain of *prejudice* or wrong *bias* on the underſtanding, it will neither perceive clearly, nor adhere firmly, to the truth; it will confound things that are different, and obſcure things that are clear. The taſk is difficult, but the reward is great.

It is therefore incumbent on every philoſopher to cultivate a diſpoſition of mind, which will make him open to conviction, and ready to acknowledge and rectify miſtakes. An obſtinate adherence to error generally ariſes from ſelf-conceit, or a bigotted attachment to a ſyſtem. True wiſdom is ever accompanied with diffidence and humility.

Lord Bacon divides the unfavourable prepoſſeſſions of the mind into four claſſes; the IDOLS OF THE TRIBE, IDOLS OF THE DEN, IDOLS OF THE MARKET, IDOLS OF THE THEATRE.*

The *idols of the tribe* are thoſe which are common to all men, ſuch as beſet the whole ſpecies; they ariſe from the principles of the human conſtitution, and may have their uſes in the preſent ſtate of human nature; but by exceſs, or defect, or wrong direction, lead us into much error. The human underſtanding reſembles a mirror of an irregular ſurface, which mixing it's own nature with the nature of things, diſtorts and perverts them. Philoſophers ſhould always endeavour to conceive things as forming part of the univerſe, and as having their appropriate office and uſe therein; whereas they are too apt to conſider them only as they have ſome particular relation to the *ſenſes*, a way by which you will never diſcover their ſyſtematical or coſmical uſe and qualities.

The *idols* common to human nature are ſo numerous, that a few only of them can be conſidered in this place: of theſe the firſt is *authority*,† by which men are prone to be led too much in their opinions.

It affixes, as it were, the ſeal of infallibility on theſe opinions, it bars the door of ſcience, and in a meaſure deſtroys the hopes of poſterity. We ought ever to preſs forward, nor ever conceive that the labours of one man can have ſet limits to human knowledge; or hearken to thoſe, who, having erected an idolatrous temple to his fame, would have us ſtop and worſhip, nor preſume to paſs the boundaries they have marked for human reaſon.‡

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* Idola tribus, idola ſpecus, idola fori, idola theatri.

† Reid on the Intellectual Powers of the Mind, p. 653.

‡ Young's Eſſay on the Powers and Mechaniſm of Nature, preface.

There never was more neceſſity than at preſent to point out the dangers ariſing from the influence of authority, as you will find ſome philoſophers*, requiring an implicit faith in the opinions they have adopted; not conſidering that while our knowledge remains imperfect, our opinions muſt be mingled with error. It is from this implicit truſt upon the credit and blind errors of others, that ſpring all thoſe *vulgar errors* cheriſhed from age to age by the blindneſs of prejudice and inveteracy of habit.

In all matters within our cogniſance, every man muſt be determined by his own final judgment, otherwiſe he does not act the part of a rational being. Authority may add weight to one ſcale, but man holds the ballance and judges what weight he ought to allow to authority. No claim can deprive us of this right, or excuſe us for neglecting to exerciſe it. *Authority*, however, has it's uſe; in the firſt part of life we have no other guide, and without a diſpoſition to receive implicitly what we are taught, we ſhould be incapable of inſtruction, and incapable of improvement. Even when judgment is ripe, there are many things in which we are incompetent judges. In ſuch matters it is moſt reaſonable to rely upon the authority of thoſe, whom we believe to be competent and diſintereſted. In matters that we have acceſs to know, authority always will have, and ought to have, more or leſs weight in proportion to the evidence on which our judgment reſts, and the opinion we have of the judgment and candour of thoſe who differ from or agree with us. Our reſpect for authority may therefore be too great, or too ſmall. The modeſt man, conſcious of his own fallibility in judging, is in danger of yielding too much to authority; the arrogant, of giving too little.

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* The following paragraphs are ſpecimens among many of the undue influence given to names.

"Sir Iſaac Newton is the perſon to whom we owe theſe obligations, and who is henceforth to be conſidered *as our only ſure guide and inſtructor.*" Again, "Newton has diſcovered the chaos, and ſeparated the light from the darkneſs; his inimitable work, the Mathematical Principles of Natural Philoſophy, contains the *true aſtronomical faith*; *and thoſe who reject it's doctrines, are the worſt of heretics*, as they ſhut their eyes againſt the cleareſt of all light, demonſtration."

2dly. The mind is apt to form imaginary relations, and to ſuppoſe a greater regularity and uniformity among things than what really exiſts. Our natural impatience is continually leading us to refer all events to certain general laws, and prevents our following the ſlow, but ſure method of inveſtigation. And though many things in nature are in ſome meaſure ſingular, or extremely diſſimilar, the mind is feigning parallels, correſpondencies, and imaginary analogies, which have no exiſtence. Arguments from analogy readily preſent themſelves to a warm imagination, while thoſe that are deduced from experiment and obſervation require ſtrong exertions of the mind, and cannot be formed without attention and application.

In the ſame manner we are apt to conceive a greater ſimplicity in nature, than there really is. To love ſimplicity, and to be pleaſed with it whereever we find it, is no imperfection, but the contrary. There is without doubt in every part of creation all the beautiful ſimplicity which is conſiſtent with the end for which it was made. The more we know, the more we diſcover the uniformity and ſimplicity in nature, when compared with the vaſt extent and variety of operations therein. But if we hope to diſcover how nature brings about it's ends merely from this principle, that it operates in the ſimpleſt and beſt way, we deceive ourſelves, and forget that the wiſdom operating in nature is more above the wiſdom of man, than man's wiſdom is above that of a child. It is indeed a maxim in philoſophy, we muſt not impute to many cauſes what can be effected by one; this principle is no doubt right, but how are we to judge what is ſimple, or what is œconomical in nature? only by endeavouring to diſcover every thing that is neceſſary to the production of this effect, and muſt uſe in our explanation every cauſe thus diſcovered, whether they be many or few.

It was believed for many ages, that all the variety of concrete bodies we find on this globe is reducible to four elements, of which they are compounded, and into which they may be reſolved. It was the ſimplicity of this theory, not any evidence from fact, that made it ſo generally received; for the more it is examined, we find leſs ground to believe it.

When a real cauſe is diſcovered, the ſame love of ſimplicity leads men to attribute to it effects which are beyond it's province. A medicine that is found to be of great uſe in one diſtemper, commonly has it's virtues multiplied till it becomes a panacea. In other branches of knowledge the ſame thing often happens. When our attention is turned to any particular cauſe capable of producing remarkable effects, there is great danger of extending it's influence, upon ſlight evidence, to things with which it has no connection.

We are in the dark with regard to the real cauſes of the greater part of the phenomena of nature, and have, at the ſame time, an avidity to know them; hence ingenious men frame conjectures, which thoſe of weaker underſtandings take for truth. The fare is coarſe, but appetite makes it go down.

3dly. The mind, when it is once pleaſed with certain things, has a natural tendency to draw all others to conſent and go along with them; and though the number of inſtances that make for the contrary is greater, yet it either does not attend to, or deſpiſes them, often rejecting them by ſome frivolous diſtinction, pointed out by a ſtrong and pernicious prejudice, in order to maintain the authority of it's firſt choice unviolated. *Diagoras*, on being ſhewed in the temple of Neptune many *votive pictures*, of ſuch as had eſcaped ſhipwreck, was aſked by his guide whether he did not acknowledge the divine power? wiſely anſwered, *Shew me, firſt, where thoſe are painted that were ſhipwrecked after having thus paid their vows?* Hence alſo in moſt caſes of ſuperſtition, as of aſtrology, dreams, judgments, &c. thoſe who find pleaſure in ſuch kind of vanities, always obſerve where the event anſwers, but ſlight and paſs by the more frequent inſtances where it fails. The imagination is ſo captivated, that the powers of reaſon are incapable of freeing it from the enchantment. This miſchief diffuſes itſelf ſtill more ſubtilly in philoſophy and the ſciences, where that which has once pleaſed infects and ſubdues all other things, though much more ſubſtantial and valuable than itſelf. The mind is always alſo more moved and excited by affirmatives than by negatives, whereas it ſhould duly and equally yield to both. In raiſing of true *axioms*, negative inſtances have the greateſt force.*

4thly. The human intellect is moſt moved and captivated by thoſe things that ſtrike and enter it at once, filling and ſwelling the imagination; but for the reſt, it feigns and ſuppoſes them in an imperceptible manner to be like thoſe few that poſſeſs the mind. We have a general diſpoſition to meaſure things leſs known and familiar by thoſe that are better known and more familiar: whereas the underſtanding is ſlow, and unwilling *to paſs*

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* See this fully ſhewn in Nov. Org. part ii. ſect. ii.

to remote and diſſimilar inſtances, whereby *axioms* are tried as it were by the fire.

This natural proneneſs to judge of things leſs known by thoſe that are familiar and better known, muſt not, however, be altogether laid aſide, as it is the foundation of all analogical reaſoning, to which we are indebted for a great part of our knowledge. It is difficult, however, to judge how far we may venture upon it. The objects of ſenſe engroſs our thoughts in the firſt part of life, and are moſt familiar through the whole of it. Hence in all ages men have been prone to give human paſſions, frailties, &c. to ſuperior intelligences. Hence the diſpoſition in men to materialize every thing, and to apply their notions of material objects to things of another nature. Hence the many crude and ill-digeſted theories on our ideas.* The miſtakes in common life, which are owing to this propenſity, are innumerable. Hence the ſelfiſh man thinks all pretences to benevolence and public ſpirit to be mere hypocriſy, and ſelf-deceit: while the generous and open-hearted eaſily believe fair pretences, and conſider men as better than they really are.

5thly. Another idol of this tribe has it's origin in the natural reſtleſsneſs of the human underſtanding, always moving, but far too often to no purpoſe, as when it is in ſearch of things beyond it's reach. There is not a greater ſource of error than in the miſapplication of our nobleſt intellectual power to purpoſes for which it is incompetent.

The works of men, and the works of God, are not of the ſame order. The force of genius may enable a man perfectly to comprehend the former. What is contrived and executed by one man, may be perfectly underſtood by another. He may from a part, conjecture the whole, or from effects may conjecture the cauſes, becauſe they are the effects of a wiſdom not ſuperior to his own.*

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* See Reid's Eſſay on the Intellectual Powers of Man, p. 654.

But the works of creation are contrived and executed by a power and wiſdom infinitely ſuperior to that of man. And when men attempt, by the force of genius, to diſcover the cauſes of the phenomena in nature, they have only a chance of going wrong more ingeniouſly. Their conjectures may appear very probable to beings no wiſer than themſelves; but they have no chance to hit the truth. They are like the conjectures of a child, how a ſhip of war is built, and how it is managed at ſea. It gratifies the pride and natural propenſity of the human underſtanding; but it is an attempt beyond our force, like that of *Phäeton*, to guide the chariot of the ſun.

Full liberty muſt be allowed to our inquiry, that natural philoſophy may acquire all the certainty and perfection of which it is capable; but we muſt not abuſe this liberty by *ſuppoſing*, inſtead of *inquiring*, by framing ſyſtems, inſtead of deducing the conſtitution of things from obſervation and experience. An attachment to ſyſtems prevents us from attending to the real ſtate of things, or makes us reject them, or interweave therewith our own conceits.

Syſtems and hypotheſes in general, framed by philoſophers out of their own ideas, and ſeparated by the mind from the truth of things, were the bane of natural philoſophy, and for centuries oppoſed the advancement of ſcience.

In all inquiries into the conſtitution of nature, human genius may combine, but it muſt not fabricate. It may collect evidence, but it muſt not ſupply the want of it by conjecture. It may diſplay it's powers, by putting nature to the queſtion by well-contrived experiments; but it muſt add nothing to her anſwers.

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* Ibid. p. 669. Maclaurin's Account of Sir Iſaac Newton's Diſcoveries, p. 7. See alſo Lecture ii. p. 59.

6thly. Another impediment and deviation of the underſtanding ariſes from the dullneſs, incompetency, and fallacies of the ſenſes. Hence the things that ſtrike the ſenſe, unjuſtly overballance thoſe that do not ſtrike it immediately. So that contemplation uſually ends with ſight, and little or no obſervation is made of things INVISIBLE. Hence all the operations of the different airs included in tangible bodies, all ſubtil organizations, and the motion of the parts, are unknown to mankind; yet *unleſs they are diſcovered and brought to light*, no great progreſs can be made in the knowledge of nature; *for it is by ſubtil matters in motion that her chief operations are performed.* Nor can inſtruments for improving and ſharpening the ſenſes be here of any great ſervice; for all true *interpretations* of nature are made by appoſite *inſtances* and experiment, *where ſenſe judges of the experiment only*, and the *experiment judges of nature and the fact.*

Idols of the den. Theſe are prejudices that take their riſe, not from the conſtitution of human nature, but from ſomething peculiar to every individual, from education, cuſtom, and a variety of other circumſtances. Our excellent logician, Lord Bacon, ſeems to have taken this appellation from *Plato*'s beautiful emblem of the *cave*; for if any one ſhould, in his infancy, be educated in a dark cave, remaining there till he was of full age, and ſhould then of a ſudden be brought into broad daylight, and behold the apparatus of heaven and earth, no doubt many ſtrange and abſurd thoughts would ariſe in his mind. And though we live, indeed, in the view of heaven, our minds are confined in the caverns of our bodies, where we receive infinite images of error and falſehood, if we do not conſtantly dwell in the contemplation of nature, as it were, in the open day-light. This emblem of *Plato* agrees well with the ſaying of Heraclitus, *That men ſeek the ſciences in their own narrow world, not in the wide one.* Further, as in a cave objects vary their appearance according to the form of the cave, and it's manner of receiving the light; ſo *Lord Bacon* conceives the mind of every man to reſemble a cave, which has it's particular form and particular manner of being enlightened, and which from theſe circumſtances often gives falſe colours, and a deluſive appearance to objects ſeen in it.

Hence the perverſion and miſapplication of reaſon, and the abuſe of learning, become the ſource of many errors. Under this head you may reckon the reaſoning from *no principles at all*; the reaſoning *from the principles of one branch of learning in the method of another*; the reaſoning *from the principles of one to the truths of another*; or laſtly, the *expecting the ſame kind and degree of conviction in the truths of one, which belong to another,* and which it does not admit. Theſe four cauſes ariſing from the abuſe of learning will account for many ſcientific errors. However various the errors of the learned may appear to be, they all originate either in the *pride* or *prejudice* of the human mind; for according to the obſervation of *Lord Bacon,* of oppoſite errors, the cauſes of erring are commonly the ſame.

Though it may appear abſurd that any one ſhould *reaſon from no principle at all,* yet is it an error of great and extenſive influence. Great are the powers of the human mind, but her *preſumption* is ſtill greater. Not content to be employed upon ſuch principles and materials as are provided for her uſe by *Providence,* and the natural ſtate of things, in a ſlow and ſober exerciſe, vainly preſuming, by an action and operation of her own, to invent others of a ſuperior order, by whoſe aſſiſtance ſhe may ſoar with a rapid wing into the poſſeſſion of the ſublimeſt truths; buoyed up into the air by theſe ſelf-inventions, ſhe attempts unbounded flights into the fertile but deluſive regions of imagination. Hence we often ſee philoſophers led by trains of ſolid reaſoning to the temple of ſplendid and deluſive errors.

The other three cauſes juſt enumerated have their origin in *prejudice* ariſing from partial and inveterate *habits*. Man is altogether the creature of *habit*; all his virtues are habits; all his vices are habits; habit has it's ſway alſo over his mind both in the elegant and ſcientific parts of learning.

As the ear is prepared and qualified by habit for the enjoyment of muſic, the eye for that of painting, and every other part of the mental and corporeal frame adapted to it's proper object; ſo is the mind prepared and qualified by habit for the ſearch and reliſh of every kind of truth.

But this ſame habit, which is the friend to all knowledge; by being too long and too cloſely confined to the ſame object, employments, and purſuits, generates a prejudice, and confirms a partiality which generally cramps and confines, and often weakens and deſtroys the powers of the mind. Being addicted to one ſet of principles, habituated to one train of reaſoning, and accuſtomed to one ſpecies of concluſions, they are diſqualified by the very habits of ſtating, reaſoning, and concluding, and by their very ſucceſs in ſome parts of learning, from proſecuting truth in others.*

Men are fond of particular ſciences and ſtudies, either when they believe themſelves the authors or inventors thereof, or becauſe they have beſtowed much pains upon them, or applied themſelves thereto. A man whoſe thoughts have been confined to a certain track by his profeſſion, or manner of life, is very apt to judge wrong when he ventures out of that track. He is apt to draw every thing within the ſphere of his profeſſion, to wreſt and corrupt every new contemplation with his habitual idea, and to judge of things by maxims which have no relation to them.

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* Tatham's Scale and Chart of Truth, vol. ii. p. 304.

Ariſtotle furniſhes us with a ſignal example of the foregoing obſervations; he made his natural philoſophy ſuch a ſlave to his *logic*, as to render it contentious, and in a great manner uſeleſs. The mere *mathematician* is apt to apply meaſure and calculation to things incapable of being meaſured: direct and inverſe ratios have been applied to meaſure human affections, and the moral worth of actions. An eminent mathematician attempted to aſcertain, by calculation, the ratio in which the evidence of facts muſt decreaſe in the courſe of time, and fixed the period when the evidence of the facts, on which chriſtianity is founded, ſhall become evaneſcent; and when in conſequence no faith ſhall be found on the earth. The ancient *chemiſts* were wont to explain all the myſteries of nature, and even of religion, by ſalt, ſulphur, and mercury.

The great and radical difference of capacities as to philoſophy and the ſciences, lies, ſays our noble author, in this; that ſome are ſtronger and fitter to obſerve the differences of things, others to obſerve their correſpondences. A ſteady and ſharp genius can fix it's contemplations, and dwell and faſten upon all the ſubtilty of differences. While a ſublime genius, with a quick conception, perceives and compares the ſmalleſt and moſt general agreement of things: both kinds eaſily falling into exceſs; the one by graſping at the dividing ſcale, the other by embracing the ſhadows of things.

To contemplate nature and bodies in their ſimplicity, breaks and grinds the underſtanding; to conſider them in their configurations and compoſitions, blunts and relaxes it. The former is ſo taken up with the particles of things, as almoſt to neglect their ſtructure: while the other views the fabrication with ſo much aſtoniſhment, as not to enter into the ſimplicity of nature. Both theſe kinds of contemplation ſhould therefore be taken up by turns, that the underſtanding may at the ſame time be piercing and capacious, and the above-mentioned inconveniences with the *idols* thence ariſing may be prevented.

Different perſons, either from temper or education, have different tendencies of underſtanding, which by their exceſs are very unfavourable to ſound judgment. Some men of genius are wrapped up in the admiration of antiquity, and contempt of whatever is modern; others go as far into the contrary extreme, and are delighted only with what is novel. Some either quarrel with what was juſtly laid down by the ancients, or deſpiſe what is juſtly advanced by the moderns. The unballanced mind of man is alwas ſhifting from one exceſs into another, and rarely knows to ſuſtain itſelf in that juſt *mean* which right reaſon and pure religion demand. It is inconceivable to thoſe who are only acquainted with the preſent ſtate of the learned world, to what an abſurd height this attachment to antiquity was formerly carried. Both extremes are highly prejudicial to philoſophy and the ſciences, as being rather an affectation of *antiquity* and *novelty*, than any true judgment. For truth is not to be derived from any felicity of *times*, which is an uncertain thing, but from the light of nature and experience, which is eternal. Theſe affectations are therefore to be laid aſide, and care be taken that the underſtanding be not hurried away with them.

Let *contemplative prudence*, ſays our incomparable author, proceed in chaſing and diſlodging the *idols of the den*, and learn to ſuſpect whatever powerfully ſtrikes and detains the mind, uſing then greater caution to preſerve your underſtanding pure and equable.

A ſpirit of prejudice and prepoſſeſſion is very detrimental to philoſophy, it admits of no improvement but what it brings from it's own fund. When a man has ſtrongly imbibed any particular notions, he inveſtigates nature not to receive information, but to find ſupport for his own opinions.

A love of novelty is alſo very injurious to real truth; the knowledge of any truth apprehended as uſeful to mankind, is pleaſing to the mind, and our eagerneſs to enjoy this pleaſure makes us often entertain a perſuaſion of knowing a thing before we really do, or upon a very weak ground. It is therefore dangerous to paſs a judgment upon a new diſcovery while it is new; we ſhould wait until time has abated the ſweetneſs of novelty, and given ſcope for reflection to flow in from different quarters. The proper ſpirit for inveſtigation, is humility, ſobriety, calm conſideration, attentive induſtry, and perſeverance.

Lord Bacon ſhews, that of various prejudices, there are none ſo troubleſome as the *idols of the market*, which inſinuate themſelves into the mind from the aſſociation of words and terms, the imperfections and the abuſe of language. Language can reach no further than our notions; and if theſe be vague and ill-defined, the words by which we expreſs them muſt be ſo likewiſe. A ſtronger inſtance of the abuſe of words can ſcarce be found than in the nomenclature of the French chemiſts,

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deſigned to prepare the mind for ſlavery by "babbling a dialect of France." For though men believe, ſays Lord Bacon, their reaſon governs words; it alſo happens, that words retort and reflect their force upon the underſtanding; whence philoſophy and the ſciences have been rendered ſophiſtical and inactive. Words are generally impoſed according to vulgar conceptions, and divide things by lines, i. e. diſtinctions or differences, that are moſt apparent to the underſtanding of the multitude: and when a more acute underſtanding, or a more careful obſervation, would remove theſe lines, to place them according to nature, words cry out, and forbid the alteration. Hence it happens that ſerious diſputes frequently terminate in controverſies about words and terms, which it were better to reduce to order by definitions. But in natural and material things, even theſe definitions cannot remedy the evil, becauſe definitions themſelves conſiſt of words, and words generate words; ſo that of neceſſity recourſe muſt be had to particular *inſtances*, their *ſeries* and *orders*.

The fourth kind of prejudices mentioned by our author are the *idols of the theatre*, which are neither conſtitutional nor ſecretly inſinuated into the underſtanding, but palmed upon it, received from fabulous theories and perverted demonſtrations, ariſing from the ſyſtems or ſects in which we have been trained, or which we have adopted. A falſe ſyſtem once fixed in the mind, becomes as it were the medium through which we ſee objects; they receive a tincture from it, and appear of a different colour from what they do when viewed by the pure light.

In Lord Bacon's method of ſtudying philoſophy there is no neceſſity for confuting the various theories; yet that the paſſage to truth may be made eaſier, and the underſtanding the more diſpoſed to cleanſe itſelf, and put away it's idols, without which true philoſophy can never be effectually promoted, (for the ſciences formed by diſtempered minds will partake of their diſtempers,) he has claſſed ſome of the more ancient kind, and given ſome account of them. He claſſes them all under three heads: 1ſt. The Sophiſtical: 2d. Empirical: and 3d. Superſtitious.

The firſt are the *ſophiſtical*, who haſtily take up vulgar things from experience, without aſcertaining their certainty, or carefully examining and weighing them, committing all the reſt of the work to thought and the diſcuſſion of the wit: theſe he compares to ſpiders, who form their webs from their own bowels to catch unwary inſects in their aerial flights. Common obſervation and obvious experiments are not of themſelves ſufficient for the foundation of a ſerviceable philoſophy; nor is the common logic an engine at all ſuited to deal with experiments, obſervation, and nature. Of theſe we have an eminent example in *Ariſtotle*, who corrupted *natural philoſophy* with his *logic*. He ſeemed to be more ſollicitous how men might defend themſelves by anſwers, and advance ſomething that ſhould be poſitive in words, than to come at the inward truth of nature; and where he had experience for his guide, to wind her round, and lead her captive to his opinions. Now as the education of the great ſchools is chiefly *Ariſtotelian*, we ſhould have a ſtrict watch upon ourſelves in all philoſophical inquiries, writings, and diſcourſes, that we are not led away with Ariſtotelian notions. All our common reaſoning ſeems infected with Ariſtotelian prejudices, ſo as to be affectedly logical and captious, rather than juſt and philoſophical, or formed upon the true nature of things.

The *empirical* philoſophers are thoſe, who labour with great diligence and accuracy, in a few experiments; and then venture to deduce theories and build up ſyſtems, ſtrangely wreſting every thing elſe to theſe experiments. Bacon compares them to inſects gathering up grain, and laying it by as they found it. The opinions produced by theſe are more deformed and monſtrous than thoſe of the ſophiſtical kind, as not being founded in the light of vulgar notions (which are in ſome degree general and univerſal); but reſt in the narrow confines and obſcurities of a few experiments: whence ſuch a philoſophy appears probable, and in a manner certain, to the men who daily converſe with theſe experiments, and thereby deprave their imagination; whilſt to others the theories appear incredible and vain. Of this you will find examples in moſt of the ancient chemical writers, in Gilbert's magnetical philoſophy, and that of many moderns, ſome of whom reſolve all difficulties by attraction, others by repulſion, &c. You can never uſe too great caution on this head, for the underſtanding is always eager, and precipitated by it's deſire of bounding or flying to general and firſt principles; thus forming theories on very feeble ground. The infinite variety of natural objects, the ſtupendous coincidence by which all agree and all differ, muſt convince you, that no vigour of judgment, or warmth of fancy, is equal to the tracing of every phenomenon to it's firſt principles, or forming an hypotheſis adequate to explaining all the operations in nature.

There is alſo danger from *ſuperſtition* and *theology* (though much leſs ſo than heretofore); for the underſtanding is as ſubject to the impreſſions of fancy as thoſe of vulgar notions: by the former it is flattered and courted, and therefore deceived. We meet with this in all theories, where firſt and final cauſes are introduced, and the intermediate ones omitted. We ſhould be careful in this caſe that we be not led thereby to canonize error, and venerate vanities. Some modern writers have ſo far indulged this ſtrange levity, as to endeavour the founding of natural philoſophy upon the firſt chapter of Geneſis, and other parts of ſacred writ; thus *ſeeking the dead among the living.*

The true philoſopher, Lord Bacon compares to the bee, that gathers the matters from the flowers of the field, from which with admirable ſkill ſhe makes her honey. He neither truſts wholly to his own underſtanding, nor contents himſelf with recording the hiſtory of mechanical experiments; but by reaſoning ſkilfully from them brings forth truth and ſcience, the great and noble production of the human faculties.

He very properly reprehends thoſe, who, upon a weak conceit of ſobriety, or ill-applied moderation, thought or maintained that a man can ſearch too far, or be too well ſtudied in the *book of God's word,* or in *the book of God's works;* but rather he ſays, let men awake themſelves, and chearfully endeavour to purſue an endleſs progreſs and proficiency in both; only let them beware, leſt they apply knowledge to pride inſtead of charity, to oſtentation inſtead of uſe. He alſo obſerves, that in the entrance of philoſophy, when the ſecond cauſes, moſt obvious to the ſenſes, offer themſelves to the mind, we are apt to cleave unto and dwell too much upon them, ſo as to forget what is ſuperior thereto: but when we paſs further, and behold the dependence, continuance, and confederacy of cauſes, and the works of providence; then, according to the allegory of the poets, we eaſily believe that the higheſt link of nature's chain muſt needs be tied to the foot of Jupiter's chair, or perceive that philoſophy, like *Jacob*'s viſion, diſcovers to us a ladder, whoſe top reaches up to the footſtool of the throne of GOD.

Falſe

Falſe ſchemes of natural philoſophy may lead to atheiſm, or ſuggeſt opinions concerning the Deity, and the univerſe, of the moſt dangerous conſequences to mankind: and you have the more reaſon to be on your guard on this head, as the philoſophers of France have, for many years, been perverting it to the moſt dire and malignant purpoſes. True philoſophy will lead you to believe in, and adore, the Supreme Being; and as it continually exhibits brighter and brighter inſtances of his wiſdom and power, it removes alſo, in part, that veil ſpread over nature, which conceals from our view, it's awful depths and majeſtic heights; and thus enables you to ſee the glories of the Almighty ſhining in this HIS exalted creation, and hence inſtructs you to raiſe your voice in praiſes to HIM, who is alone worthy to receive glory and honour and power; for it is by *Him* that all things were created, and it is by *Him* that they are continually preſerved.

"That ONE *great and univerſal* MIND, who made all things by his power, and preſerves them in his goodneſs, is the firſt and only cauſe, operating at all times and in all places, and producing, by an exertion of his will, all the various phenomena of the material ſyſtem. This firſt and univerſal cauſe, however, in the ordinary adminiſtration of his providence, hath condeſcended to employ *ſecond cauſes* as the inſtruments of his will, by which he acts; which ſecond cauſes HE hath alſo appointed in his wiſdom to operate through every part of his creation by *general laws.* To trace the hand of the ALMIGHTY through all his works, to inveſtigate theſe *general cauſes*, and to erect them into the *laws of phyſics*, is the ſublime, the delectable, and honourable employment of the natural philoſopher." *

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* See Tatham's admirable work, entitled, Scale and Chart of Truth, p. 133.

To explain, therefore, with certainty the phenomena of nature, to remove their obſcurities, and obſerve their influence and connection, is the great buſineſs of philoſophy; for this purpoſe the obſerver muſt obtain certain fixed points, which may ſerve as ſignals to conduct him in the difficult path he has undertaken, and prevent his wandering too far from the main road.

Phyſical logic does not conſiſt in argument, but in diſcovering facts, not what agrees with principles, but the principles themſelves. There is a meaning and deſign in every operation of nature. The natural philoſopher endeavours to diſcover this meaning, and interpret theſe deſigns by a careful obſervation of her ſteps; but if the mind haſtily imbibes, and without diſcrimination treaſures up the firſt notices of things, error will ever prevail and remain uncorrected; for if theſe primary notices are vitiated, confuſed, or inaccurate, thoſe derived from them will be equally defective, and the knowledge built thereon like a magnificent ſtructure on a bad foundation.

The philoſopher, therefore, avoids the demonſtration of *ſyllogiſm*, becauſe it continually lets nature and reality ſlip through it's fingers, and wreſts the works thereof to make them ſquare with the works of men; whereas the works of men ought to be ſubmitted and formed according to the works of nature; ſo that *logical* demonſtrations applied to phyſical matters are only the play of words. He therefore takes *induction* for the form of demonſtration, as it guards the ſenſes, preſſes nature cloſe, and rules over her works.

Inſtead of flying immediately from the ſenſes, and particulars to generals, (about which diſputes always turned) and deriving intermediate principles from theſe in a ſhort but precipitate manner, a manner fit for controverſy, but unfit to cloſe with nature, he endeavours to raiſe propoſitions by degrees, and thus arrive at *general axioms*, axioms not notional, but well defined, and ſuch as are conformable to the nature of things.

Axioms raiſed, ſays *Lord Bacon*, by argumentation can never be uſeful in diſcovering new works; for there is no mode of raiſing axioms, but by a legitimate and proper form of induction, capable of ſeparating experience, and concluding of neceſſity after all the proper rejections and excluſions are made.

Beginning then with phenomena, the philoſopher endeavours to trace out the proximate cauſes, and riſing gradually from particular cauſes, he proceeds to the more general, and ſo on by ſure and uninterrupted ſteps, man comes without ſtop or gap to the top round, or unity of nature; from whence he may deſcend in a contrary order, and from eſtabliſhed principles explain the phenomena derived from them. In no other mode can we be ſure that we aſſume the principles which really obtain in nature, or that any ſyſtem we may compoſe, is not mere dream and illuſion.

Thus you ſee that the proceſs of *induction* is an aſcent from particular premiſes to general concluſion. The evidence of ſuch general concluſion is only *probable*, not *demonſtrative*; yet if the induction be ſufficiently copious and properly conducted, it forces conviction as ſtrongly as demonſtration.

Mere reaſoning will carry a man but a very little way in moſt ſubjects; but by obſervation and experiments properly conducted, the ſtock of human knowledge may be continually enlarged.

Before the philoſopher forms his judgment, he muſt, by accurate experiments, and diligent obſervations, ſearch out how far the phenomenon he is inveſtigating is influenced by others, and this in all poſſible caſes and circumſtances, by what modifications it is affected, and in what proportion it is combined and connected with other effects: he will thus endeavour to obtain an exact notion of the object of his reſearches, and marching ſolidly towards truth, he will interrogate nature with ſucceſs; being careful to ſtop where no experimental proof can be procured, and not preſuming where the ſubtilty of nature carries things out of his reach; for he might as well pretend to build without materials, as to form without obſervation and experiment a rational ſyſtem of natural ſcience.

General principles cannot be eſtabliſhed with ſolidity, without numerous experiments, and many obſervations on the ſame individual ſubject, and then on different ſubjects of the ſame ſpecies: their probability is greater as the obſervations on which they are founded are more numerous, and accurately performed: all exceptions being then made, a ſound and ſerviceable portion of truth will be left behind as a *general axiom*. "By a repetition of the ſame induſtrious proceſs and laborious inveſtigation, he advances from general to more general, till at laſt he is able to form a few of the moſt general, with their attributes and operations, into *axioms, or ſecondary principles*, which are the well-founded *laws* enacted and enforced by the God of nature."

Having diſcovered any of theſe laws or cauſes, it becomes the buſineſs of philoſophy to trace them in all their effects, and to predict ſimilar appearances from ſimilar previous ſituations. The philoſopher, by knowing what will be the reſult of putting things into a variety of circumſtances, becomes maſter of the powers of nature, and can apply them to uſeful purpoſes of life; and thus does knowledge, as Lord Bacon obſerves, become *power.*

The ancient logic, far from correcting what was wrong, ſerved rather to fix error in the mind than open the way to truth. LORD BACON had to begin anew, and lay down ſuch rules for the workings of the mind, as would never leave it to itſelf; as if the buſineſs was to be performed by a machine (an organum), which would ſettle the degrees of certainty, and contrive ſuch ways of ſubmitting things to the ſenſes, as that a true judgment might be formed concerning them. Being convinced by careful obſervation, that the *human underſtanding* perplexes itſelf, and does not make a ſober and advantageous uſe of the real helps within it's reach; and that this occaſioned manifold ignorance and many inconveniences; he employed his utmoſt endeavours to reſtore and cultivate a juſt and legitimate familiarity between the mind and things, by raiſing a new *art*, in which *reaſon* and *experience* ſhould be joined together for the improvement of philoſophy. This eſtabliſhment of a new logic is called, by our author, *the art of interpreting nature.*

The end of the new logic is, as we before obſerved, to find not *arguments* but *arts*; not what agrees with principle, but principles themſelves; not probable reaſons, but *plans* and *deſigns* of works; a different intention produces a different effect. In one the adverſary is conquered by *diſpute*, in the other nature by works. And ſuitable to this difference of the deſign, is the nature and order of the demonſtrations, which here is purely inductive. Thoſe therefore who determine not to conjecture, but to find out and know, not to invent *fables* and *romances of worlds*, but to look into and diſſect the nature of this *real world*, muſt only conſult things themſelves. Nor can any force of genius, ſtretch of thought, or ſubtilty of argument, be ſubſtituted for labour, ſearch, and inſpection.

The knowledge and power of man are coincident; for while he is ignorant of cauſes, he can produce no effects. Nature is only to be conquered by ſubmiſſion, by condeſcending to inquire into and obſerving her methods of working, as a ſervant would learn thoſe of his maſter. No power of man can break the natural chain of cauſes; ſo that the only method whereby man can *rule* nature, muſt depend upon learning her ways. And good hopes can only then be conceived of the ſcience, when by continued ſteps, *like real ſtairs uninterrupted or unbroken*, men ſhall aſcend from particulars to *leſſer axioms*, and ſo on to middle ones, and from theſe again to higher, and laſtly, to the higheſt of all; and thus diſcover the *forms* or *active laws of nature, by which all things exiſt and have their effects.* To the diſcovery of theſe laws we are continually directed by Lord Bacon, as to a thing that alone will conſtitute a juſt and univerſal theory, and direct to an extenſive practice. *His Inſtauration*, or ſcheme for rebuilding arts and ſciences, depends upon the *diſcovery of forms.* But theſe forms or *laws* can be truly inveſtigated by no other means than that of *induction.*

It is therefore of the utmoſt importance in philoſophy to aſcertain, as accurately as poſſible, the general powers in nature, to determine their cauſes, and trace their conſequences; for as the phenomena of nature are infinite, and the faculties of the human mind are limited, theſe phenomena, when conſidered as unconnected with other facts, convey but little inſtruction. The infinite not being the object of ſcience, till the forms or laws of nature be known, by careful obſervation and accurate induction, no progreſs can be made in natural philoſophy.

Hence the neceſſity of collating and connecting corresponding facts, and the advantage of reducing them to certain axioms, and applying theſe to account for other phenomena; that we may at laſt advance to a knowledge of the moſt general laws that regulate the ſyſtem of operations in nature. But though we may be warranted to conſider all the phenomena that we find connected with theſe general laws, and manifeſtly depending upon them, as ſo many facts explained, ſo many truths known and underſtood; yet we ought not to overlook ſuch phenomena, as are not reducible to thoſe general principles; but ſhould view them as ſimple and ſeparate facts, and treaſure them up till a more enlarged experience, and more accurate obſervation lead us to the diſcovery of thoſe powers of nature to which they are to be referred.

This method of *reaſoning* founded on experiments and obſervation, by which the general ideas and *forms* of natural philoſophy are invented, is purely and excluſively *inductive*. The ſchools are not the theatre in which this philoſophical logic is diſplayed. It does not delight in external appearances and oſtentatious formality. It retires from the clamour of verbal diſputation into the retreat of the elaboratory and obſervatory, where in ſilent inveſtigation it lays the foundation of ſubſtantial learning; and as it mixes with experiment and obſervation, it is incapable of being adequately deſcribed by words, but is beſt ſeen and underſtood by attending it in the act, and purſuing it through every ſtage of the analytical progreſſion.*

After men had laboured in the ſearch of truth near 2000 years by the help of ſyllogiſms, *Lord Bacon* propoſed the method of *induction* as a more effectual engine for that purpoſe. His *Novum Organum*

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* Tatham's Chart and Scale of Truth, p. 137.

ganum gave a new, uſeful, and remarkable turn to the thoughts and labours of the inquiſitive, and may be conſidered as forming a grand æra in the progreſs of human reaſon.*

Neither experience nor experiment muſt, however, be conſidered as ſuch infallible guides, as to juſtify our refuſing information from any other quarter: for they never make us thorough maſters of the ſubject. We may know enough for our preſent uſes, but can never know that there is not more to be learnt, beſides what we have diſcovered. We can only obſerve what effects they work upon our ſenſes, or upon one another, and from thence *induce* imperfectly the powers belonging to them, and cauſes operating upon them, but can make no juſt deduction that there are not other powers and cauſes whoſe effects we have never yet experienced.

The greateſt part of human knowledge reſts upon probable evidence. Indeed we can have no other for general truths, which are contingent in their nature, and depend upon the will and ordination of the maker of the world. He governs the world he has made by general laws. The effects of theſe laws in particular phenomena, are open to our obſervation, and by obſerving a train of uniform effects with due caution, we may at laſt decypher the law of nature by which they are regulated.

Such is the genuine logic of phyſical learning, which has before it ſuch a vaſt extent and variety of ground, as is ſufficient to employ the joint and confederated labours of philoſophy of different ages and countries, aſſiſted by the largeſt collection and beſt arrangement of natural hiſtory, which is the proper foundation of natural philoſophy. From this ground experience takes it's ſlow but ſteady courſe; it firſt, ſays Lord Bacon, lights the candle, and then by that candle ſhews the way, beginning with regular and well conducted experiments, not ſuch as are vague and prepoſterous, from whence it derives axioms; and then from axioms well eſtabliſhed deſcends to new experiments.

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* Reid on the Intellectual Powers of the Mind.

"But however numerous and extenſive the experiments and obſervations may be, they muſt of neceſſity come ſhort of the number and extent of nature, which in ſome caſes will defeat all poſſibility of their coextenſion, and in others, by it's diſtance, lies out of the reach of their immediate application. In order, therefore, to make his law of general uſe, and ſtretch it over the whole extent of nature, the philoſopher is obliged to have recourſe to *analogy*, by which he can lengthen out his inductions, which are properly confined to the number of experiments and obſervations actually made, to all others of the ſame kind; concluding the axiom to hold good of all, and that not only for the preſent, but alſo for the future, till it be either confirmed and rectified, or elſe contradicted by better experiments, and a more extenſive and complete induction." For if in reaſoning about natural things, we were confined wholly to experience, our knowledge muſt fall ſhort of being general, for it would be confined to thoſe alone on which we made our experiments.

"This is that juſt and philoſophic method of reaſoning, which ſound logic preſcribes in this, as well as in other parts of learning; by which, through the ſlow but certain road of experiment and obſervation, the mind aſcends from appearances to qualities, from effects to cauſes; and, by a fair *induction* from many particular ſubjects extended by *analogy*, forms *general propoſitions* concerning the powers and properties of phyſical bodies. What can fairly be deduced from facts duly obſerved, or ſufficiently atteſted, is genuine and pure; it is the voice of God, and no fiction of human imagination.

The view of nature, which is the immediate object of ſenſe, is very imperfect, and of a ſmall extent; but by the aſſiſtance of art, and the help of our reaſon, is enlarged till it loſes itſelf in an infinity on either hand. The immenſity of things on the one ſide, and their minuteneſs on the other, carry them equally out of our reach, and conceal from us the far greater and more noble part of phyſical operations. As magnitude of every ſort, abſtractly conſidered, is capable of being increaſed to infinity, and is alſo diviſible without end; ſo we find that, in nature, the limits of the greateſt and leaſt dimenſions of things are actually placed at an immenſe diſtance from each other. We can perceive no bounds of the vaſt expanſe in which natural cauſes operate, and can fix no border or termination of the univerſe; and we are equally at a loſs when we endeavour to trace things to their elements, and to diſcover the limits which conclude the ſubdiviſions of matter. The objects which we commonly call great, vaniſh when we contemplate the vaſt body of the earth: the terraqueous globe itſelf is ſoon loſt in the ſolar ſyſtem: in ſome parts it is ſeen as a diſtant ſtar: in great part it is unknown, or viſible only at rare times to vigilant obſervers, aſſiſted, perhaps, with an art like to that by which Galileo was enabled to diſcover ſo many new parts of the ſyſtem. The ſun itſelf dwindles into a ſtar; Saturn's vaſt orbit, and the orbits of all comets, croud into a point, when viewed from numberleſs places between the earth and the neareſt fixed ſtars. Other ſuns kindle light to illuminate other ſyſtems, where our ſun's rays are unperceived; but they alſo are ſwallowed up in the vaſt expanſe. Even all the ſyſtems of the ſtars that ſparkle in the cleareſt ſky, muſt poſſeſs a ſmall corner only of that ſpace over which ſuch ſyſtems are diſperſed, ſince more ſtars are diſcovered in one conſtellation by the teleſcope, than the naked eye perceives in the whole heavens. After we have riſen ſo high, and left all definite meaſures ſo far behind us, we find ourſelves no nearer to a term or limit; for all this is nothing to what may be diſplayed in the infinite expanſe, beyond the remoteſt ſtars that ever have been diſcovered. If we deſcend in the ſcale of nature towards the other limit, we find a like gradation from minute objects to others incomparably more ſubtil, and are led as far below ſenſible meaſures as we were before carried above them, by ſimilar ſteps that ſoon become hid to us in equal obſcurity. We have ground to believe, that theſe ſubdiviſions of matter have a termination, and that the elementary particles of bodies are ſolid and uncompounded, ſo as to undergo no alteration in the various operations of nature or of art. But from microſcopical obſervations that diſcover animals, thouſands of which could ſcarce form a particle perceptible to the unaſſiſted ſenſe, each of which has it's proper veſſels, and fluids circulating in thoſe veſſels; from the propagation, nouriſhment, and growth of thoſe animals; from the ſubtilty of the effluvia of bodies retaining their particular properties after ſo prodigious a rarifaction; from many aſtoniſhing experiments of chemiſts; and eſpecially from the inconceivable minuteneſs of the particles of light, that find a paſſage equally in all directions through the pores of tranſparent bodies, and from the contrary properties of the different ſides of the ſame ray; it appears, that the ſubdiviſions of the particles of bodies deſcend by a number of ſteps or degrees that ſurpaſſes all imagination, and that nature is inexhauſtible by us on every ſide. Nor is it in the magnitude of bodies only that this endleſs gradation is to be obſerved. Of motions, ſome are performed in moments of time, others are finiſhed in very long periods; ſome are too ſlow, and others too ſwift, to be perceptible by us. The tracing the chain of cauſes is the moſt noble purſuit of philoſophy; but we meet with no cauſe but what is itſelf to be conſidered as an effect, and are able to number but few links of the chain. In every kind of magnitude, there is a degree or ſort to which our ſenſe is proportioned, the perception and knowledge of which is of the greateſt uſe to mankind. The ſame is the ground work of philoſophy; for though all ſorts and degrees are equally the object of philoſophical ſpeculation, yet it is from thoſe which are proportioned to ſenſe that a philoſopher muſt ſet out in his inquiries, aſcending or deſcending afterwards as his purſuits may require. He does well indeed to take his views from many points of ſight, and ſupply the defects of ſenſe by a well-regulated imagination; nor is he to be confined by any limit in ſpace or time: but as his knowledge of nature is founded on the obſervation of ſenſible things, he muſt begin with theſe, and muſt often return to them to examine his progreſs by them. Here is his ſecure hold; and as he ſets out from thence, ſo if he likewiſe trace not often his ſteps backwards with caution, he will be in hazard of loſing his way in the labyrinths of nature.

From this ſhort view of nature, and of the ſituation of man, conſidered as a ſpectator of it's phenomena, and as an inquirer into it's conſtitution, we may form ſome judgment of the project of thoſe, who, in compoſing their ſyſtems, begin at the ſummit of the ſcale, and then by clear ideas pretend to deſcend through all it's ſteps with great pomp and facility, ſo as in one view to explain all things. The proceſſes in experimental philoſophy are carried on in a different manner; the beginnings are leſs lofty, but the ſcheme improves as we ariſe from particular obſervations to more general and more juſt views. It muſt be owned, indeed, that philoſophy would be perfect, if our view of nature, from the common objects of ſenſe to the limits of the univerſe upwards, and to the elements of things downwards, was complete; and the powers or cauſes that operate in the whole were known. But if we compare the extent of this ſcheme with the powers of mankind, we ſhall be obliged to allow the neceſſity of taking it in parts, and of proceeding with all the caution and care we are capable of, in inquiring into each part. When we perceive ſuch wonders, as naturaliſts have diſcovered, in the minuteſt objects, ſhall we pretend to deſcribe ſo eaſily the productions of infinite power in ſpace, that is at the ſame time infinitely extended and infinitely diviſible! Surely we may rather imagine, that in the whole there will be matter for the inquiries and perpetual admiration of much more perfect beings.*

It is not, therefore, the buſineſs of philoſophy, in our preſent ſituation in the univerſe, to attempt to take in at once, in one view, the whole ſcheme of nature; but to extend, with great care and circumſpection, our knowledge by juſt ſteps from ſenſible things, as far as our obſervations or reaſonings from them will carry us, in our inquiries concerning either the greater motions and operations of nature, or her more ſubtil and hidden works.

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* Maclaurin's Diſcoveries of Sir Iſaac Newton, p. 15.

Among thoſe who have purſued the path pointed out in the *Novum Organum*, Sir ISAAC NEWTON holds the firſt rank. It was on this plan he eſtabliſhed his account of the ſyſtem of the world upon the beſt aſtronomical obſervations on the one hand; while on the other, he performed himſelf, with the greateſt addreſs, the experiments, by which he was enabled to pry into the ſecrets of nature.

He has given us two incomparable treatiſes, his Mathematical Principles of Philoſophy, and his treatiſe of Optics. In the firſt, he deſcribes the ſyſtem of the world, and ſhews the powers which govern the celeſtial motions. Theſe are extended from the center of the ſun to the utmoſt altitude of the higheſt comet. In the ſecond he treats of light, one of the moſt potent agents in nature.

The firſt rule of philoſophiſing laid down by this great man is this: *No more cauſes, nor any other cauſes of natural effects, ought to be admitted, but ſuch as are both true, and ſufficient for explaining their appearances.* This is a golden rule. If a philoſopher, therefore, pretends to ſhew you the cauſe of any natural effect, whether relating to matter or mind, conſider firſt, whether there be ſufficient evidence that the cauſe aſſigned does really exiſt. If there be not, reject it with diſdain, as a fiction, which ought to have no place in genuine philoſophy. If the cauſe aſſigned really exiſts, conſider in the next place, whether the effect it is brought to explain neceſſarily follows from it: unleſs it has theſe two conditions, it is good for nothing.

The ſecond rule of the great Newton is this: *That natural effects of the ſame ſort are to be accounted* *for by the ſame cauſes.* This rule is founded on a juſt appreciation of analogy, on the uniformity of the proceedings in nature. Thus it conſiders the deſcent of a heavy body towards the earth in Europe as an effect of the ſame ſort with the deſcent of a heavy body towards the earth in America. To ſuch effects, therefore, ſimilar cauſes ought to be aſſigned. The motion of the moon round the earth, of the ſatellites round Jupiter or Saturn, and of the primary planets round the ſun, are effects of the ſame kind. Therefore whatever you find to be the cauſe of one of theſe motions, you may conclude to be the true cauſe of the others.

It is eaſy for you to obſerve, that this rule is deduced from the latter part of the foregoing one. Effects of the ſame kind may be accounted for by the ſame cauſes. It is right, therefore, to aſſign the ſame cauſes to ſimilar effects; becauſe we ſhould otherwiſe multiply cauſes without reaſon, and ſhould introduce more than are ſufficient for the appearances of nature.

Newton's third rule is built upon induction and analogy, and conſiders *thoſe qualities that are found invariably to belong to all bodies, upon which we can make experiments, as qualities belonging to all bodies whatſoever.*

There are many bodies on which we cannot make experiments; yet if we have frequently made experiments upon other bodies, that fall immediately under our notice, and find them invariably endued with certain qualities, we may be allowed by analogy to extend our concluſion to all other bodies, and thus make it univerſal: a way of reaſoning, that is agreeable to the harmony of things, and to the old maxim, aſcribed to *Hermes*, and approved by the obſervation and judgment of the wiſeſt philoſophers, *That what paſſes in the heavens above is ſimilar and analogous to what paſſes on the earth below.**

Thus all bodies, that we have obſerved, are found to gravitate towards one another; they endeavour, if they are near the earth, to deſcend by their weight to the earth's center. Now though we have not tried the experiment on every ſtone, or upon every piece of lead that we ſee, yet from what we have tried, we conclude that all of them have this ſame quality. And if this concluſion be juſt, when extended thus far beyond our own obſervation, we may extend it ſtill farther. No one, after what he has experienced in all ſorts of bodies that he has been uſed to, can reaſonably doubt, whether other bodies, of different ſorts, are not poſſeſſed of gravity as well as theſe; and from what he has obſerved in all bodies, where he can make experiments, he may conclude, that this property of gravity belongs to all bodies univerſally, and that the moon gravitates towards the earth. It is thus that we are enabled, by a ſufficient number of particular experiments, to draw general concluſions.

If you look back into the ſtate of philoſophy in the different ages, you will learn from the hiſtory of every period, that as far as philoſophers conſulted nature, and proceeded on obſervation, they advanced in true knowledge; but as far as they endeavoured to build ſchemes on any other foundation, they only multiplied diſputes and errors.

Wiſely, therefore, does Lord Bacon conſider

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* Maclaurin's Sir Iſaac Newton's Diſcoveries, p. 22.

natural philoſophy as a vaſt pyramid, that ought to have the hiſtory of nature for it's baſis, an account of the powers and principles that operate in nature for it's ſecond ſtage, and the formal and final cauſe of things for it's third ſtage. But as for the ſummit of this pyramid, the ſupreme of nature, *opus quod operatur Deus a principio uſque finem*, he doubts whether it will ever be attainable by man.

I cannot offer to your attention, as a concluſion to this Lecture, any thing more pertinent to the reſearches you are engaged in, than the devout aſpirations of a diſciple of the *Stagyrite*, * only ſo far altered as to render them more conformable to the plan of this work.

Aſſiſt us, O Lord, our heavenly Father, with the light of that *reaſon* by which thou lighteneſt the world; by which grace and beauty is diffuſed through every part, and the welfare of the whole is uniformly upheld. So teach us to know ourſelves, that we may attain that knowledge, which is worth attaining.

Teach us to be fit actors in that drama, where thou haſt allotted every being, great and ſmall, it's proper part, the due performance of which is the one chief end of it's exiſtence.

Enable us to curb *deſire*, and keep it always within the bounds of rectitude. Be our firſt work to eſcape from *wrong opinion* and *bad habit*; that the mind being rendered ſincere, and the heart incorrupt, we may with ſafety proceed to ſeek our genuine good and happineſs.

When we are thus previouſly exerciſed, thus duly prepared, let not our *love* there ſtop where it firſt begins; but inſenſibly conduct it, by thy inviſible influence, till it is conjoined to thee, in whom only it can find what is adequate and full. Teach us to love *thee*, and thy divine *adminiſtration*; to regard the univerſe as our true and genuine country; and let the ſtreams of our beneficence be extended to the whole of mankind. Be it our endeavour by an humble ſpirit, a gentle deportment, and an unfeigned good nature, to ſoften every care, alleviate every pain, and thus render all around us happy.

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* Mr. Harris.

Let our life be a continued ſcene of *acquieſcence* and of *gratitude*, of gratitude for what we *enjoy*, and of acquieſcence in what we *ſuffer*; and enable us to co-operate with cheerfulneſs in whatſoever thou ordaineſt; that ſo we may know no other will than thine alone, and that the harmony of our *particular* minds with thy *univerſal* may be ſteady and uninterrupted through the period of our exiſtence.

Turn our minds from all that is abject, ſervile, and evil, and enable us to embrace and cheriſh only what is generous, lovely, fair, and Godlike.

Let it be our ſtudy and delight to behold in the ſilent mirror of contemplation, thoſe forms which are hidden to human eyes; that animating *wiſdom*, which pervades and rules the whole; that *order*, irreſiſtible, immutable, ſupreme, which leads the willing, and compels the averſe, to co-operate in their ſtation to the general welfare; that magic divine, which, by an efficacy paſt comprehenſion, can transform every appearance, even the moſt hideous, into beauty, and exhibit all things fair and good to *thee, who art of purer eyes than ever to behold iniquity*; the ſole and only Lord and Saviour, a never-ceaſing, ever-overflowing ocean of meekneſs, delight, goodneſs, patience, and mercy, ever giving forth the ſame gifts of goodneſs and truth, of light and love, bleſſing and joy, to angels and men.

LECTURE XV.

ON OPTICS.

THE advances made in the knowledge of optics in the laſt and preſent age, are ſuch as do honour to human nature and philoſophy. *The theory of light and colours* by Sir *Iſaac Newton*, is a piece ſo excellent for invention, for judgment in conducting experiments, and for drawing the proper concluſions from them, that had it been *Newton*'s ſingle work, it would not only have done honour to him, but to the country that gave him birth.* Of the faculties called the five ſenſes, ſight is without doubt the moſt noble; the rays which miniſter to this ſenſe, and of which without it we could never have had the leaſt conception, are the moſt wonderful and aſtoniſhing part of the inanimate creation.

Of this you will be ſatisfied when you conſider their extreme minuteneſs; their inconceivable velocity; the regular variety of colours which they exhibit; the invariable laws according to which they are acted upon by other bodies, in their reflexions and refractions, without the leaſt change of their original properties; and the facility with which they pervade bodies of great denſity, and of the cloſeſt texture, without reſiſtance, without diſturbing one another, without giving the leaſt ſenſible impulſe to the lighteſt bodies.

Heat and light may be conſidered as the children of fire, as kindred qualities produced by the ſame cauſe, ſometimes exerting their powers ſeparately, ſometimes united. We are, however, very ignorant of the intimate combinations of light, and it's mode of acting upon different bodies. Experiments upon vegetables give us reaſon to believe, that light combines with certain parts thereof, and that the green of their leaves, and the various colours of their flowers, are chiefly owing to this combination: for plants, which grow in darkneſs, are perfectly white, languid, and unhealthy: to make them recover vigour, and acquire their natural colours, the direct influence of light is neceſſary. Somewhat ſimilar takes place even upon animals, and mankind degenerate to a certain degree, when confined too cloſely, or employed in ſedentary manufactures. Though the ſun is many millions of leagues from you, yet you *ſee* it as *evidently*, and *feel* it's influence as *powerfully*, as if it were within your reach: it is *within your exiſtence*. It ſupplies comfort and life to your animal body and life; and you could not ſurvive an hour without it's influence and operations.

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* Sir J. Pringle's Diſcourſes, p. 233.

Light is diffuſed on every ſide from it's fountain the ſun: joined with air, it gives beauty and fruitfulneſs to the earth, ſupports vegetable and animal life, and the various kinds of motions throughout the ſyſtem of nature. By their manifold and beneficial operations, as well as by the beauty and magnificence they produce, they point us to HIM who in ſcripture is called the GLORY OF GOD, by whom all things were made and are upholden. And the *firmament*, the expanſion of the celeſtial elements, *ſheweth his handy work*, not only as *Creator*, but as *Redeemer* of the world. The labours of our inſtructors in the natural world know of no intermiſſion, but inceſſantly lecture us in the ſcience of divine wiſdom. The ſun ſhines forth by day, the moon and ſtars by night; though they are not endowed like man with the faculty of ſpeech, yet they addreſs themſelves to the mind of the intelligent beholder in another way, by the way of picture and repreſentation.

Light introduces all nature to us, the trees, the flowers, the cryſtal ſtreams, and azure ſky: the fixed parts of nature are eternally entombed beneath the light; and we ſee nothing in fact but a creation of colours; nothing is an object of viſion but light; that which we call body or ſubſtance, that which reflects the various colours of light, lies hid beneath the appearance, is wrapt in impenetrable obſcurity. *Matter*, at firſt ſight, ſeems to be the only being we have correſpondence with, to meet us every where; but when we examine, it ſhrinks like a phantom behind perception; we know it not; the cloſer we inveſtigate it's nature, the more it glides away from us, and all that we can at length aſcertain, only points it out as a ſhadowy ſhrowd, under which SOVEREIGN POWER retires from plain view, and acts by regular laws.

The eye is the inſtrument by which we perceive the effects of light; it's ſtructure, it's appurtenances, the various contrivances for performing all it's internal and external motions, clearly point it out to be the work of Divine Wiſdom; and he muſt be very ignorant of what has been diſcovered concerning it, or of a very ſtrange caſt of underſtanding, who can ſeriouſly doubt, whether or not the rays of light, and the eye, were made for one another with conſummate wiſdom and perfect ſkill in optics.

If you were to ſuppoſe an order of beings endued with every human faculty but that of ſight, how incredible would it appear to ſuch beings accuſtomed only to the ſlow information of touch, that by the addition of an organ conſiſting of a ball and ſocket of an inch diameter, they might be enabled in an inſtant of time without changing their place to view the diſpoſition of a whole army, or the order of a battle, the figure of a magnificent palace, or all the variety of a landſcape? If a man were by feeling to find out the figure of the peak of Teneriffe, or even of St. Peter's church at Rome, it would be the work of a life-time.

It would appear ſtill more incredible to ſuch beings as we have ſuppoſed, if they were informed of the diſcoveries that may be made by this little organ in things far beyond the reach of any other ſenſe; that by means of it we can find out our way upon the pathleſs ocean; that we can traverſe the globe, determine it's figure, it's dimenſions, and delineate every region; that we can meaſure the planetary orbs, and count the number of the heavenly hoſt.

Would it not appear ſtill more aſtoniſhing to ſuch beings, if they ſhould be farther informed, that by means of this ſame organ we can perceive the tempers and diſpoſitions, the affections and paſſions of our fellow-creatures, even when they want moſt to conceal them? That by this organ we can often perceive what is ſtrait and crooked in the mind as well as the body; that it participates of every mental emotion, the ſofteſt and moſt tender, as well as the moſt violent and tumultuous; that it exhibits theſe emotions with force, and infuſes into the ſoul of the ſpectator the fire and the agitation of that mind in which they originate? To many myſterious things muſt a blind man give credit. If he will believe the relations of thoſe that ſee, his faith muſt exceed that which the poor ſceptic derides as impoſſible, or condemns as abſurd.* It is not, therefore, without reaſon, that the faculty of ſeeing is looked upon as more noble than the other ſenſes, as having ſomething in it ſuperior to ſenſation, as the ſenſe of the underſtanding; the language of intelligence.

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* Reid's Inquiry into the Human Mind, p. 152, 155.

The evidence of reaſon is called *ſeeing*, not feeling, ſmelling, taſting; nay, we expreſs the *divine knowledge* by *ſeeing*, as that kind of knowledge which is moſt perfect in ourſelves.

Truth is of the nature and eſſence of GOD, incapable of a verbal definition, but may be illuſtrated by the ſimilitude of *light*. Between the objects of the mind and corporeal things, the objects of outward ſenſe, there may be found in many reſpects a very natural and juſt analogy, as it is, indeed, natural to expect; every *corporeal* form being but the image or reſemblance of ſome *mental* form. Hence you find in ſacred writ, *light* applied as a name to the Supreme Being; for as the *ſun* is the *fountain* of *external light* to this viſible world, ſo is the *Divine Mind* the fountain of intelligence or intellectual light. Thus alſo the different kinds of GOOD which run throughout the whole external univerſe, may be conſidered as beams emitted forth from the *goodneſs* of the *Divine Being*; and though the *intellectual ſun*, who enlightens the whole *intelligent* or ſpiritual world, be uniform in his eſſence, like uncoloured light; yet as he beams around on all things, without exception or intermiſſion, his rays take a diverſity of tints from the diverſity of objects on which they fall, or the different lights in which the ſame object is conſidered: or, as a *ray* of the *ſun*, that *ſublime* and *ſignificant* emblem of TRUTH, paſſing through a priſm, is divided into a beautiful variety of ſhades and colours, ſo that ray of truth, which is ſhed down from heaven on the human mind, as it paſſes through different mediums of knowledge, differs in ſtrength and degree, and exhibits an illuſtrious ſpecimen of that beauty and variety in appearance and effect which diſtinguiſh all the works of God. The influence of our *intellectual ſun* never ceaſes, nor will it ever miſs of accompliſhing it's divine ends in all ſuch minds as *open* themſelves to *receive* the aid of his benign *irradiation.*

I ſhall not, perhaps, find a more ſuitable opportunity of illuſtrating to you the words of the apoſtle, (and by this illuſtration pointing out to you one of the great ends of natural philoſophy,) that *the inviſible things of God are clearly ſeen from the creation of the world, being* UNDERSTOOD *by the things which are made.* The whole natural world, throughout the ſacred oracles, is referred to as a figure of the ſpiritual. You will find this ſubject placed in a very clear light by the Rev. Dr. Tatham,[*] in vol. ii. of his "Scale and Chart of Truth," a work to which I have already referred you. In this dark and ſublunary ſtate, wedded to ſenſe, immured in body, and involved in matter, we poſſeſs no faculties by which we can form any *immediate* conception of God and ſpiritual beings.[†] Between the viſible and inviſible worlds an impaſſable gulph is fixed, an impenetrable chaſm, through which not a ray of celeſtial light can *directly dart.* All our information, therefore, of things that are divine muſt be conveyed through an *indirect* channel.

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[*] Tatham's Scale and Chart of Truth, vol. ii. p. 121; vol. i. p. 185. See alſo the works of Lord Bacon, Dr. Horne, Biſhop of Norwich, and thoſe of the Rev. William Jones.

[†] *Plato* has a moſt beautiful paſſage on this head, ſaying, "That they who contemplate an eclipſe of the ſun, unleſs they view the image of the ſun in water, or ſome ſuch thing, loſe their own *eye-ſight*, by gazing attentively upon an object brighter than it can bear." That is, the mind by contemplating too cloſely the *τα οντα*, and endeavouring by it's own internal energy to behold them as they are in themſelves, will be dazzled and ſtupified; but by having recourſe to ſenſible objects, and reaſoning from an analogy in nature, it may contemplate them without being impaired.

You know that by analogy in human language we transfer material impreſſions to mental ſubjects, and can thereby communicate and conſider theſe with certainty and preciſion; ſo, by a ſimilar, but higher transfer from things which are human, material, or mental, to thoſe which are divine, human language is converted into an indirect but certain inſtrument of this celeſtial communication.

OUR LORD, in condeſcenſion to the capacity and apprehenſion of mankind, hath graciouſly and abundantly employed this analogy as a medium to render us capable of receiving the myſteries of religion. This divine analogy is founded, like the human, upon a ſimilitude conſiſting in a *perfect reſemblance* and *correſpondent reality* between the terreſtrial things and ideas, which are the direct objects of the human intellect, and thoſe celeſtial truths of which it can have no direct conception; and it is expreſſed by transferring the words which ſtand for the terreſtrial things, and the ideas to celeſtial truths, which words are to be taken in their plain and obvious, not figurative ſenſe; ſo that the compariſon is founded on ſomething *real* as well as ſimilar; from which real ſimilarity, reaſon deduces a juſt and true correſpondence.*

Inſtead of giving men new and ſpiritual ideas of heavenly things, different from thoſe they have by nature, and inſtead of uſing a ſpiritual language or mode of communication calculated directly to expreſs heavenly truths, (which would be to change their nature at once) this analogy takes men as they

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* This is not, ſays Biſhop Butler, an *apparent* and *metaphorical ſimilitude*; it is the ſubſtituting the *idea* or *conception* of one thing to *ſtand* for and *repreſent* another, on account of a *true reſemblance* and *correſpondent reality* in the *very nature* of the things compared. It is defined by Ariſtotle an *equality* or *parity* of reaſoning, though the parity of reaſoning is rather built on the ſimilitude and analogy, and conſequent to them, than the ſame with them.

they are, and only transfers their words and ideas from earthly to heavenly ſubjects, by which divine and wonderful expedient, the *inviſible things of God are* CLEARLY *ſeen, being* UNDERSTOOD *by the things that are made.*

By this method of divine revelation, ſo *neceſſary*, ſo *real*, ſo *clear*, and certain, the Almighty has, as it were, bowed the heavens, and come down, in wonderful condeſcenſion to the blindneſs and imperfection of human reaſon, ſpeaking to us of himſelf in our own ideas and words, with the utmoſt familiarity, *as a man ſpeaketh to his friend*, and enabling us to ſpeak of him as far as we are concerned, with all reverence and adoration, but with as much eaſe and certainty as of each other.

In the explication of his myſteries (ſays Lord Bacon, our divine philoſopher) God vouchſafed to deſcend to the weakneſs of our capacity, ſo expreſſing and unfolding them to us as they may be beſt comprehended by us, inoculating, as it were, his revelations upon the conceptions and notions of our reaſon; and ſo applying his inſpirations to open our underſtanding, as the figure of a key is fitted to the wards of a lock. We ought not, however, on this account, to be wanting to ourſelves; for ſeeing God makes uſe of the faculty and functions of reaſon in his divine illuminations, we ought every way to improve the ſame, in order that we may be more capable to receive and entertain ſuch holy myſteries.

OUR LORD, who is himſelf the fountain and conductor of *truth*, is repreſented in the ſacred oracles *as* the SUN, the fountain of LIGHT, and *as* the DAY-SPRING FROM ON HIGH, the harbinger of LIGHT; and of theſe apt ſimilitudes familiar to all, even without an explanation, he often availed himſelf, expreſſing *truth* by the ſignificant emblem of LIGHT; and the LIGHT OF LIFE.

His

HE *by whom all things were made* hath delegated to the *ſun* the power of enlightening the material ſyſtem, while he hath reſerved to HIMSELF the office of giving light and knowledge by his eternal TRUTH to the mind of man. But whether he acts through the *inſtrumentality* of his creatures, or more *immediately* from himſelf, he is uniform and conſiſtent in his operations; ſo that one part of his creation is always illuſtrative of another.

The ſun, in performing his daily ſplendid office, beams forth light and life throughout our ſyſtem, and proclaims, in language known to all, *it's Maker's* ſacred glory, whoſe power ſupplies the never-failing fountain with it's endleſs beams, and makes it a repreſentative of his inviſible glory. Thus as the SUN ſheds his light over the material creation to be apprehended by the eye, ſo TRUTH is the light ſhed down from heaven to be apprehended by the intellect, given to illumine every ſubject natural and moral, corporeal and ſpiritual, as far as they are qualified by their different natures to convey it to the human mind, or rather perhaps ſo far as the human mind is *qualified* to receive it from them. For the difficulty of receiving truth does not exiſt ſo much in the ſubjects as in ourſelves; and truths which are the ſtrongeſt, may ſometimes ſhine upon our mind with the weakeſt force.

In order to inſtruct us, the ſacred ſcripture always places ſome natural object before the eye of the underſtanding; and as the *viſible* world is throughout a pattern of the *inviſible*, the figures of the ſacred writers built upon the images of nature, are as extenſive as the world itſelf. The world being thus an image or ſhadow of heavenly things, *natural philoſophy*, when employed in unfolding the works of creation, and applying them to their true end, is a *ſchool* in which *God* is the teacher; and all the objects of ſenſe in heaven and earth, and under the earth, are the letters of an univerſal language, in which you and all mankind have a common intereſt.

Words are changeable, language has been confounded, and men in different parts of the world are as unintelligible to one another as barbarians: but the viſible works of creation are not ſubject to any ſuch confuſion, they ſpeak to us the ſame language as they ſpoke to Adam, and their language will laſt as long as the world ſhall remain.

Thus, for example, if you take the word GOD, you have a ſound which gives you no idea; and if you trace it through all the languages of the world, you find nothing but arbitrary ſounds with great variety of dialect and accent, all of which ſtill leave you where you began, and reach no farther than the ear. But when it is ſaid, *God is a ſun and a ſhield*, then *things* are added to words, and you underſtand the extent of the power and the influence of the Being, ſignified by the word God; you conceive *him* to be the author of light to the underſtanding, the fountain of life to the ſoul, it's ſecurity againſt all terror, it's defence againſt all danger. Such is the difference between the language of *words* and the language of *things*. If an image is preſented to the mind, when a ſound is heard by the ear, then we begin to underſtand, and a ſingle object of our ſight in figurative acceptation will give you a larger and more inſtructive leſſon than ever could be conveyed by all the poſſible combinations of ſounds.

In the preceding Lectures on fire you have ſeen how every thing ſubſiſts, and is preſerved in the midſt of an element capable of deſtroying and conſuming all things, and yet by it's ſpontaneous action, it never deſtroys any thing.

I have now to treat of another agent; LIGHT is a property of fire; by it's operation it makes us paſs in the twinkling of an eye from a ſtate of the thickeſt darkneſs to that of the brighteſt day; it gives us as it were a new exiſtence, making us go out of ourſelves, and enter into communion and commerce with the moſt diſtant objects. Heat and light are undoubtedly the offſpring of fire; but we are equally unable to draw the line of ſeparation, or to trace the bond that unites them. You need not be ſurprized at theſe various modifications of the ſame fluid, when you reflect on what you have already ſeen in this world, where *beauty* is ſo *diverſified*, where *being* is ſo *multiform*, and yet where one and the ſame face of things is ever preſented to your view.

As the *eye* among the organs of body, ſo *optics* among the branches of natural philoſophy, is the moſt noble, curious, and uſeful; and this whether it is treating of ſimple viſion, of that through glaſſes, or of the effects of mirrors, all ſtill relates to the eye, and you are intimately concerned in all the phenomena of which it treats. If you caſt your eyes on a large plain, and run rapidly over all the objects thereon, in an inſtant their image is exactly painted at the bottom of your eye; if you look through a teleſcope at a diſtant object, it appears as if it were within a few inches of the eye.. Does age weaken the ſight? a convex glaſs reſtores it again; if the eye be ſo formed as not to be capable of viewing diſtant objects, a concave glaſs remedies the defect. Have you occaſion for heat beyond the ſtrength of the furnace? optics will inſtruct you how to obtain it from the ſolar rays. With a priſm in your hand you decompoſe thoſe rays, and ſhew that the rays of light which appear to us uncoloured, conſiſt of ſeven primitive colours.

Amongſt the various inventions of human art, there are none ſo juſtly entitled to your admiration, as thoſe which enlarge the powers of viſion. And the diſcovery of *optical inſtruments* may be eſteemed amongſt the moſt noble, as well as amongſt the moſt uſeful gifts which the SUPREME ARTIST has conferred on man. For all admirable as the *eye* came out of the hands of HIM who made it, yet no organ of the animal frame hath HE permitted to be ſo much aſſiſted by human contrivance, not only for the uſes and comforts of life, but for the advancement of natural ſcience, whether as in *microſcopes*, by giving form and proportion to the minute parts of bodies (as it were to the atoms of nature) imperceptible before; or, by contracting ſpace, as by the *teleſcope*, and, as by magic art, bringing to view the grander objects of the univerſe, the immenſe diſtances of which had either diſguiſed their aſpect, or rendered them quite inviſible.*

Yet ſo ſingular are the diſpoſitions of men who term themſelves philoſophers, that you will find them on the one hand denying the exiſtence of *all ſpiritual beings* and *ſpiritual agency*; and on the other, ſooner than own and acknowledge the unity of deſign and wiſdom, that is evident in all parts of creation, they will embrace the greateſt abſurdities, and make fire and light to be mere *qualities*. That light is, however, the action of a material, real ſubſtance, will become very evident to you by a few conſiderations.

1ſt. The motion of light is progreſſive, like all other bodies; and it has been proved by aſtronomers, that it takes about ſeven or eight minutes in paſſing from the ſun to the earth. This diſcovery was firſt made by *Monſ. Romer*, who having obſerved, that the eclipſes of the *ſatellites of Jupiter* appeared ſooner or later than they ought by theory, according as the earth was nearer to, or farther from, Jupiter, concluded from thence that the motion of light was not inſtantaneous; and by obſerving the different times of the appearances of theſe eclipſes, according to the different diſtances of the earth from Jupiter, diſcovered the time it took up. This theory was further confirmed by a notable diſcovery of Dr. *Bradley*, of an apparent motion of the fixed ſtars, and elegantly accounted for by the motion of light.

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* Sir John Pringle's Diſcourſes.

From Dr. Bradley's obſervations it appears, that light is propagated as far as from the ſun to the earth in 8 minutes 12 ſeconds. And it likewiſe appears, that the velocity of light is uniform and the ſame, whether original, as from the ſtars, or reflected, as from the ſatellites of Jupiter.

2. Light may be ſtopped, or reſiſted, in it's paſſage from one place to another by the interpoſition of an opake body, as other fluids are ſtopped in their courſes by the oppoſition of any ſolid ſubſtance.

3. Like all other bodies in motion, it may be turned out of it's rectilinear courſe, and have the determination of it's motion changed; it may be collected into a ſmall, or ſcattered through a large ſpace.

4. It acts upon the organs of animals, and upon all other bodies, in a ſimilar manner to other fluid ſubſtances, ſtriking them with a determined force, communicating to them a certain degree of motion, and ſeparating their component parts.

The velocity of light being known, we ſhould be able to eſtimate the magnitude of it's particles, if we were in poſſeſſion of good obſervations of the effect of their momentum. For example, it is found that a ball from a cannon at it's firſt diſcharge flies with a velocity of about a mile in 8 ſeconds, and would therefore arrive at the ſun in 32 years, ſuppoſing it to move with unremitted velocity. Now light moves through that ſpace in about 8 minutes, which is two million times faſter. But the forces with which bodies move are as their maſſes multiplied by their velocities: if therefore the particles of light were equal in maſs to the two millionth part of a grain of ſand, we ſhould be no more able to endure their impulſe than that of ſand when ſhot point blank from a cannon.*

DEFINITIONS.

The cauſe and nature of viſion is properly the ſubject of that part of philoſophy which is called by the name of *optics.* But as light is a principal inſtrument in effecting viſion, the word optics is uſed in a more extenſive ſenſe, and every thing in philoſophy is looked upon as a part of optics, which relates to the nature and qualities of light.

When the word OPTICS is uſed in the ſtricter ſenſe for the theory of viſion, the ſcience of optics is divided into two parts; one part is called *dioptrics*, and the other *catoptrics.*

The laws of *refraction*, and the effects which the refraction of light has in viſion, are the ſubject of *dioptrics.*

The laws of *reflexion*, and the effects which the reflexion of light has in viſion, are the ſubject of *catoptrics.*

Theſe diſtinctions will however be of little uſe to us, nor will it be worth our while in theſe Lectures to keep the branches of optics diſtinct from each other.

Whatever is ſeen, or beheld by the eye, is by opticians called an *object.*

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* Nicholſon's Introduction to Philoſophy, vol. i. p. 256.

They conſider every *luminous object* as made up of a vaſt number of minute points; and that each of theſe points, by an unknown power, ſends forth rays of light *in all directions*, and is thus the center of a ſphere of light extending indefinitely on all ſides. To render this clearer, conſider this ſmall brilliant object that I place upon the table, and you will find, that you can ſee it from any part of the room; it is therefore evident, that rays of light muſt proceed from all parts of it, and extend indefinitely on all ſides.

By a *ray* of light, is uſually meant, the leaſt particle of light that can either be intercepted alone, whilſt all the reſt are ſuffered to paſs, or that can be let paſs alone, whilſt all the reſt are intercepted.

Any parcel of rays diverging from a point, conſidered as ſeparate from the reſt, is called a *pencil of rays.*

By a *medium*, in the language of opticians, is meant any pellucid or tranſparent body, which ſuffers light to paſs through it. Thus water, air, a diamond, and glaſs, are called mediums.

One medium is ſaid to be more *denſe* than another, when it contains more matter in the ſame bulk and ſize: thus glaſs is more denſe than water, water is more denſe than air.

A ſmall object, or phyſical point of an object, conſidered as propagating light towards a certain part, is ſometimes called a *radiant*, or *radiating point.*

Thoſe rays which proceed from any point at a very great diſtance, may be conſidered as *parallel* rays; for the greater the diſtance of the point from whence rays flow, the nearer do they approach a parallel direction.

OF THE GENERAL PRINCIPLES ON WHICH OPTICAL DEMONSTRATIONS ARE FOUNDED.

To illuſtrate and explain ſome of the general principles of optics, I ſhall darken this room, and only admit the light by a ſmall hole: oppoſite to the hole I ſhall place a white ſcreen. Now if you look at the ſcreen, you will obſerve thereon a picture of all the exterior objects which are oppoſite to the hole, with all their natural colours: the colours are faintly depicted; the images of the objects that are ſtationary, as houſes, trees, &c. are fixed and ſtationary in the picture; while the images of thoſe that are in motion, as thoſe of horſes, &c. are ſeen to move. You obſerve that the image of every object is *inverted*; this is occaſioned by the rays of light croſſing each other as they paſs through the hole. The ſun ſhines this moment on the hole, as you may ſee by the luminous ray proceeding from it to the ſcreen. Now if either of you will place your eye in this ray, you will find that your eye, the ſun, and the hole, are in one and the ſame ſtrait line. It is the ſame with every other object which is depicted on the ſcreen. The images of the objects are ſmaller in proportion as the objects are further from the hole.

Let us now conſider a few among the many important inferences that may be deduced from the foregoing experiment.

It muſt be evident to you, that *light moves or acts in a ſtrait line*; for you ſaw that your eye, the image of the object, and the object, were always in a right line. This is alſo plain from the ſhadows which opake bodies caſt; for if the light did not deſcribe ſtrait lines, there would be no ſhadow: it is equally plain from lights finding no paſſage through bent tubes.

As the rays of light are conſtantly propagated in right lines from luminous bodies, whenever I have occaſion to repreſent a ray of light, I ſhall do it by a ſtrait line reaching from a luminous body to the body illumined; that is, I ſhall ſpeak of the line which the ray deſcribes, as if it was the ray itſelf.

It is manifeſt alſo that light conſiſts of parts both ſucceſſive and cotemporary, becauſe in the ſame place you may ſtop that which comes one moment, and let paſs that which comes preſently after; and at the ſame time you may ſtop it in any one place, and let it paſs in any other. In other words, the light which falls upon an object all at once, at the ſame inſtant, is *cotemporary*; the light which from time to time continues to fall on an object is *ſucceſſive*, conſiſting of parts following one another.

A ſecond inference deducible from our experiment is, *that a luminous point may be ſeen from all places to which a ſtrait line can be drawn, without meeting with an intervening obſtacle.* This muſt be evident to you, when you remember that the picture of an object in motion in theſe experiments was viſible as long as it was in a line with the hole and ſcreen.

It follows from hence, that *a luminous point*, by ſome unknown power, *ſends forth rays in all directions*, and may be conſidered *as the center of a ſphere of light extending indefinitely on all ſides.*

This you may underſtand ſtill better by looking at *fig.* 1, *pl.* 1; where you find the point O of the dart is viſible to an eye placed in either of the ſituations A, B, C, D, E, F, G.

If you conceive ſome of theſe rays to be intercepted by a plane, then is the luminous point the ſummit of a pyramid, the body of which is formed by the rays proceeding therefrom; the baſe is the intercepting plane.

The image of the ſurface of an object on the ſcreen, is alſo the baſe of a pyramid of light, the ſummit of which is the hole. The rays which form this pyramid croſs at the hole, and there form another pyramid, of which the hole is again the ſummit, but the ſurface of the object is the baſe.

An object is viſible, becauſe all it's points are radiant points. Rays of light are inceſſantly propagated from every phyſical point of an object, otherwiſe the whole object would not be viſible; and that all at once, and to all poſitions of the eye.

For whereſoever a ſpectator is placed with reſpect to a luminous body, every point of that part of the ſurface which is turned towards him, is viſible: each point is therefore a radiant point, emitting rays in all directions; and thoſe rays only are ſtopped in their paſſage by an interpoſed object, which would be intercepted upon the ſuppoſition that the rays move in right lines.

Another inference which you will make, is this, *that the particles of light are indefinitely ſmall*; for the rays which proceed from the points of all the objects oppoſite to the hole, paſs through it, without confounding or embaraſſing each other. Exquiſitely minute they muſt be, when myriads can move all manner of ways without impinging one another; and that this is the caſe, you cannot doubt, ſince different bodies, and different parts of the ſame body, are diſtinctly viſible at the ſame time. How curious muſt be the texture of the eye to be ſenſible of theſe ſmall impulſes, and to diſtinguiſh at the ſame time thoſe from different objects!

If you make a hole with a pin in a piece of paper, and look through it, you ſee all the objects that are before you, be they ever ſo many; now ſince theſe objects, and each point of theſe objects become viſible by means of the rays of light coming from thence to the object, you may form ſome idea of their extreme minuteneſs. If a common tallow candle be lighted, and ſet by night on a high tower, it may be ſeen all round at the diſtance of half a mile from the tower: wherefore there is no place within a ſphere of a mile diameter in which the eye can be placed, where it will not receive ſome rays from this ſmall flame. Rays of light will paſs without confuſion through a ſmall puncture in a piece of paper, from ſeveral candles in a line parallel to the paper, and form diſtinct images on a ſheet of paſteboard placed behind the paper.

Every ray of light carries with it the image of the point from which it was emitted.[*]

If therefore all the rays coming from any point are united in the ſame order in which they proceeded, or were emitted, there will be a perfect repreſentation or image of that object, at the place where they are thus orderly united.

Another property in the rays of light is their REFLEXIBILITY, or diſpoſition of being turned back into the medium from whence they came; and in this they obſerve the ſame mechanical laws with other bodies in their reflexions, that is, *the angle of reflexion is always equal to the angle of incidence.* The truth of this poſition may be confirmed by many experiments; one or two will be ſufficient. Let us return to our dark room, and I ſhall, by means of a mirror without, let a beam of ſolar light paſs through the hole upon this part of the floor; where the beam falls I put a looking glaſs; I now fill the room with duſt to render the beam of light more viſible, and you ſee that it is reflected back into the air; and that the inclination of the reflected beam is exactly the ſame as that of the incident beam. This law may be confirmed by another eaſy experiment, which I will ſhew you in the next room. Here is a graduated ſemicircle, at the center of which is a ſmall piece of looking-glaſs. I place a ſmall object on the graduated edge of the ſemicircle, and on the oppoſite quadrant thereof, and exactly at the ſame angle, I place the ſight. Now if either of you look through the ſight, you will ſee the object; but if you remove the ſight-piece a little higher or lower, you will not perceive the object.

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[*] De la Caille, Leçons d'Optique, p. 24.

OF REFRACTION.

There is another property of light, which is it's *refrangibility*, or diſpoſition to be *refracted*, or turned out of it's ſtrait courſe, in paſſing *obliquely* out of one medium into another of different denſity.

This *refraction* is greater or leſs, that is, the rays are more or leſs bent and turned aſide from their path, as the medium through which they paſs is more or leſs denſe. Thus, for inſtance, the rays are more refracted in paſſing from air into glaſs, than from air into water; and glaſs is you know much more denſe than water; the denſer the medium, the more the rays are bent, and approach a perpendicular let fall upon it's ſurface. I would be underſtood always to ſpeak of the rays which fall obliquely upon theſe mediums; for thoſe rays which fall perpendicularly do not ſuffer any deviation, the *refraction only taking place when the rays fall obliquely*, and is ſo much greater as their incidence is more oblique, and the medium more denſe. After having taken the new direction, the ray again proceeds invariably in a ſtrait line, till it meets with a different medium, when it is again turned out of it's courſe.

Take an empty baſon, and at the diameter of the bottom fix marks at a ſmall diſtance from each other; then take it into the dark room, and let in a ray of light; and where this falls upon the floor, place your baſon, ſo that it's marked diameter may point towards the window, and ſo that the beam may fall on the mark moſt diſtant from the window. This done, fill the baſon with water, and you will obſerve that the beam which before fell upon the moſt diſtant mark, will now by the refractive power of the water be turned out of it's ſtrait courſe, and will fall two or three, or more marks nearer the center of the baſon.

Make the water in the baſon muddy, but not ſo much ſo as to deſtroy it's tranſparency, which you may eaſily do, by dropping therein a few drops of milk, or diſſolving in it ſome grains of ſaccharum ſaturni; then fill the room with duſt, and the beam of light will be very viſible, both in it's paſſage through the air and the water, and you will obſerve very diſtinctly three beams, that of *incidence*, which in coming through the hole, falls obliquely on the water; that of *reflexion* from the ſurface of the water, making the angle of reflexion equal to that of incidence; and that of *refraction*, which from the ſurface where it was bent, moves on in a ſtrait line to the bottom of the baſon. All things remaining the ſame, place a ſmall piece of looking-glaſs at the bottom of the baſon, where the *refracted* beam falls, and it will thereby be reflected back again through the water, and in paſſing out of the water into the air will be again refracted or turned out of it's courſe.

Another, though very common experiment, will give you a clear idea of the power of refraction; place a piece of money at the bottom of this baſon, and walk back therefrom till you cannot ſee the piece of money; let ſome water be poured into the baſon; and as before you could not ſee the piece of money *where it was*, you will now ſee it *where it is not*. It is not your eye that has changed place, but the ray of light has taken a new direction in paſſing from the water into the eye, and ſtrikes your eye as if it came from the piece of money. This experiment ſeldom fails to ſurpriſe thoſe, who are unacquainted with the properties of light; as they do not comprehend how the filling the veſſel with water can make them ſee an object placed at the bottom, and which was not viſible to them before, being concealed by the edge of the veſſel.

The advantages we derive from the refraction of light are ineſtimable: without this property we ſhould have figured glaſſes in vain, and teleſcopes and microſcopes would not have exiſted. The refraction of light at the ſurfaces of tranſparent bodies was taken notice of by the ancients. *Ariſtotle* has a problem concerning the apparent curvity of an oar in water. And *Archimedes* is ſaid to have written on the appearance of a ring or circle under water. *Alhazen* the Arabian, and *Vitellio*, thought that the angles of incidence and refraction were in a given ratio; but the proportion they laid down being found erroneous in large angles, the ſubject was examined more ſtrictly by the moderns. Kepler among the reſt made ſeveral experiments concerning it, and though he miſſed his aim, his attempts and conjectures were uſeful to others. After the invention of the teleſcope, this ſubject being thought more valuable than before, was farther purſued; and *Snellius* found out the truth: but *Deſcartes* was the firſt who publiſhed, that the *ſines of incidence and refraction* (and not their angles) *are in a given ratio*.

In explaining this ſubject, as well as in other parts of optics, I muſt have recourſe to diagrams, as the theory will require all your attention; but you will not, I hope, permit the thorns and briars which interrupt the path of ſcience, to prevent your proceeding therein; for whatever is *good* can only be obtained by *labour*; and ſcience, like virtue, diſdains the *ſlothful* and the *negligent*.

Let B C, *pl.* 1, *fig.* 2, repreſent the ſurface of water, or any other tranſparent medium denſer than air. Let A be the point of incidence, in which any ray coming through the air from F, falls upon the ſurface of the water, where it is refracted from it's ſtrait courſe A K in the line A G. About A as a center with the radius A F deſcribe the circle B F C K E; at the point of incidence A, erect a perpendicular A D, and produce it downward to E; from F upon the line A D, let fall the perpendicular F H, and from G upon A E, let fall the perpendicular G I.

The *angle* F A D, which the incident ray F A makes with the perpendicular D A, is *the angle of incidence*. The line F H is the *ſine* of the angle of incidence F A D.

The *angle* G A E, which the refracted ray G A makes with the perpendicular A E, is the *angle of refraction*. The line G I is the *ſine* of the angle of refraction.

The angle K A G contained between the line of direction of an incident ray, and the direction of the ſame ray after it is refracted, is *the angle of deviation*.

Theſe things being underſtood, I may now mention to you the laws of refraction, which have by repeated experiments been found to be general and without any exception.

1. *The angles of refraction and incidence lie in one and the ſame plane*, that is, in the plane drawn through the incident ray, and the perpendicular at the point of incidence.

2. *The rays of light are always refracted when they paſs* OBLIQUELY *from one medium into another, whoſe denſity is different from that of the firſt.*

3. *A ray of light falling obliquely upon the ſurface of a denſer medium is refracted towards the perpendicular,* that is, ſo that the angle of refraction be leſs than the angle of incidence: on the contrary, *the refraction out of a denſer medium into a rarer, as out of glaſs into air or water, is made from the perpendicular,* ſo that the angle of refraction be greater than the angle of incidence.

4. When a ray of light is refracted out of air into a given medium, or out of a given medium into air, the *ſine of the angle of incidence is to the ſine of the angle of the refraction in a given ratio*; in other words, there is a certain and immutable law or rule by which refraction is always performed; and that is this: whatever inclination a ray of light has to the ſurface of any medium before it enters, the degree of refraction will always be ſuch, that the proportion between the ſine of the angle of it's incidence, and that of the angle of it's refraction, will always be the ſame in that medium.

Hence if that proportion be known in any one inclination of the incident ray, it is known in all inclinations, and thereby the refraction in all caſes of incidence on the ſame refracting ray may be determined.

When a ray of light is refracted out of air into glaſs, the ſine of incidence is to the ſine of refraction as 31 is to 20, or as 3 to 2 nearly; or out of air into water, as 4 to 3. Hence the ſine of incidence is to the ſine of refraction, when a ray paſſes out of water into glaſs, as $\frac{3}{4}$ to $\frac{20}{31}$, or as 93 to 80.

5. *A ray of light cannot paſs out of a denſer medium into a rarer, if the angle of incidence exceeds a certain*

a certain limit;* that is, when the ſine of incidence has a *greater* proportion to radius, than it has to the ſine of refraction.

A ray of light will not paſs out of glaſs into air, if the angle of incidence exceeds 40° 11′, the ſine of which is $\frac{20}{31}$ parts of the radius; or out of glaſs into water, if the angle of incidence exceeds about 59° 20′. Refraction will be changed into reflection.

In general, the denſeſt mediums reſiſt the action of light leſs than thoſe that are more rare, the angle of refraction being ſmaller than that of incidence: and on the other hand, the rareſt mediums ſeem to reſiſt it leſs: and it has been laid down as a law, that all bodies have their refractive powers proportional to their denſities, excepting ſo far as they partake more or leſs of ſulphureous oily particles. Mr. Briſſon has ſhewn, in the memoirs of the academy of ſciences for 1777, that the refractive power of inflammable bodies compared together does not follow the ratio of their denſities.

6. *All refraction is reciprocal.* If a ray of light is refracted in paſſing out of one medium into another; then, if that ray was to return back again, it would be refracted juſt as much the contrary way: or if the refracted ray become the incident ray, then the incident ray will become the refracted one.

When the angle of incidence is increaſed, the correſponding angle of refraction will alſo be increaſed. If two angles of incidence be equal to each other, the angles of refraction will be alſo equal. In the ſame manner, if the one be diminiſhed, the other alſo will be diminiſhed; ſo that if one

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* Theſe laws, &c. are demonſtrated upon the principle, that light is an homogeneal ſubſtance; and though light will appear to be compounded of ſeveral rays, yet the principles of refraction, &c. are true when applied to rays of any one ſort.

one of theſe angles becomes infinitely ſmall, the other becomes ſo alſo.

The direction of a ray is not changed, if it moves through a medium terminated by two ſurfaces parallel to each other; for as much as it is turned towards any ſide at it's entrance, ſo much is it exactly turned the other way as it goes out of the ſaid medium.

While a ray moves in the ſame uniform medium, it does not change it's direction.

OF THE FORCE AND INTENSITY OF LIGHT.

In a free medium the force and intenſity of light propagated in parallel rays is always the ſame.

For in ſuch a medium there is nothing to impede it's progreſs, hinder it's action, retard it's velocity, or change it's direction.

In a free medium the force and intenſity of the light, which is propagated by rays proceeding from the ſame point, are in an inverſe ratio of the ſquares of the diſtances from this point. This is manifeſt from the principles of geometry, and I ſhall ſoon render it evident to you by experiment.

It ſcarce, however, wants any experimental proof; for light radiating from a center, it's intenſity muſt decreaſe, as all rays do that proceed from a center; i. e. muſt neceſſarily become thinner and thinner, continually ſpreading themſelves, as they paſs along, into a larger ſpace, and that in proportion to the ſquares of their diſtances from the body; that is, at the diſtance of two ſpaces, they are four times thinner, or leſs intenſe, than they are at one, and ſo on, becauſe they ſpread themſelves in a twofold manner, upwards and downwards, and ſideways.

If the light which flows from a point, paſſes through a ſquare hole, as b c d e, *fig.* 3, *pl.* 1, be received upon a plane B C D E placed parallel to the plane of the hole; and the diſtance A B be double of A b; then the length and breadth of the ſhadow

B D will each be double the length and breadth of the plane b d, and treble when A B is treble of A b, and ſo on; as you may eaſily prove by the light of a candle placed at A.

Hence luminous bodies, or thoſe that ſhine with their own light, are vaſtly brighter than opake bodies illuminated by them; for opake bodies diſperſe the light falling upon them in all manner of ways: whence ſuppoſing all the light to be reflected, the quantity received by the eye from the opake body, compared with that received from the luminous body, is only as the viſible illuminated ſurface of the opake body to the ſurface of an hemiſphere, whoſe radius is the diſtance of the opake body from the eye; ſuppoſing the breadth of the pupil to be the ſame in both caſes, and that the ſum of the diſtances of the opake body from the eye, and from the luminous body, differs inſenſibly from the direct diſtance of the luminous body from the eye.

Hence the light of the full moon at a medium is about 300,000 times fainter, or rarer, than the ſun's light, when at the ſame height above the horizon, all other circumſtances being the ſame, as will appear by comparing the moon's apparent diſk to the ſurface of a hemiſphere. Whence it is eaſy to conceive, that ſince we can bear the ſun's heat, we cannot be ſenſible of any from the moon.

" Though accurate methods may be uſed for inveſtigating the intenſity of the moon's light, they are too abſtruſe for our Lectures. But the following conſideration is level to every capacity: when the *moon* is viſible in the day-time, it's light is ſo nearly equal to that of the lighter thin clouds, that it is with difficulty diſtinguiſhed amongſt them. It's light continues the ſame during the night; but the abſence of the ſun permitting the aperture of the pupil of the eye to dilate itſelf, it becomes more conſpicuous."

"It follows therefore, that if every part of the ſky were equally luminous with the moon's diſk, the light would be the ſame as if in the day-time it were covered with the above-mentioned thin cloud. This day-light is conſequently in proportion to that of the moon, as the whole ſurface of the viſible hemiſphere is to the ſurface of the moon, that is, nearly as 90,000 to 1."*

We do not know any medium that is *free*, or *perfectly tranſparent*; even the air, the moſt rare and tranſparent we are acquainted with, is full of opake particles that impede the light; this is manifeſt from the phenomenon of a beam of light let in through a ſmall hole in a room, which beam is viſible like a *luminous cone* from every part of the room. This ſhews, that the whole light does not go forward in it's rectilinear courſe, but that at every point of the medium through which it paſſeth, ſome part of it is reflected every way; for the viſibility of the luminous cone is cauſed by this reflection. *The greater faintneſs of the ſun and the moon*, when near the horizon, than when elevated higher up, ſhews alſo that their light is more obſtructed, the tract of air and vapours being longer in one caſe than the other. The loſs of light in paſſing through glaſs is ſtill greater.

The ſurface alſo of bodies both tranſparent and opake, being for the moſt part uneven, it neceſſarily follows, that abundance of light is diſſipated even by bodies the moſt tranſparent, ſome being reflected, ſome refracted towards different parts by their uneven ſurfaces, whilſt other parts are refracted and reflected with ſome uniformity. This accounts for a perſon ſeeing *through* water, and his image being reflected by it at the ſame time; and ſhews why, in the duſk, the furniture in a room may be ſeen by the reflection of a window glaſs, whilſt objects that are without are ſeen through it.

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* Nicholſon's Introduction to Natural Philoſophy, vol. i. p. 166.

The quantity of light contained in any pencil is continually diminiſhed, the greater the diſtance from the radiant; and this diminution is greater or leſs, according to the greater or leſs degree of opacity in the medium through which it paſſes.

This makes it impoſſible to aſſign exactly the different proportions of the denſity of light, at different diſtances from the radiant; but in all caſes, the decreaſe of the denſity of light is greater than the ſquares of the ſaid diſtances. And this is the reaſon why objects appear leſs bright, the farther they are from the ſpectator.

If none of the rays were ſtopt in their paſſage, the degree of brighneſs of the picture of an object upon the retina, would be the ſame at all diſtances between the eye and the object, ſuppoſing the aperture of the pupil of the eye to remain the ſame. For in that caſe the magnitude of the picture upon the retina, and the denſity of light, would increaſe or decreaſe together in the ſame proportion, viz. reciprocally as the ſquare of the diſtances of the eye from the object; and therefore the denſity of the light upon the retina would be invariable at all diſtances. For *example*; when the eye approaches as near again to the object, the picture upon the retina becomes quadruple; and the quantity of light received from the object through the ſame aperture of the pupil at half the diſtance is alſo quadruple; and this being equally ſpread over four times the ſurface of the retina, the light is juſt as denſe as before, when the object was at twice the diſtance.

Luminous bodies ſhining in the dark, as a *lamp* or *torch*, &c. emit to very great diſtances much more light than in that caſe is neceſſary for viſion: and though their light ſuffers a continual diminution by the heterogeneity of the medium, the farther it goes; yet there being ſtill more left than is neceſſary for viſion, their ſplendor is not ſenſibly increaſed or diminiſhed, by leſſening or increaſing their diſtances.

Light is not only diverted out of it's courſe by reflection from the bodies it meets with, but a great part of it is alſo frequently ſuffocated, or as it were deſtroyed by them; for it is manifeſt, that black or dark bodies reflect much leſs light than others of lighter colours; and it is probable that no bodies reflect all they receive.

The power of the eye to diſcern objects without inconvenience by different quantities of light is very extenſive; for not only objects of different colours placed in the ſame light are ſeen with equal eaſe, but even objects ſo ſmall as the letters of a book may be diſtinguiſhed and read by a clear moon-light. Now admitting the ſurface of the eye's pupil to be ten times greater in a weak than in a ſtrong light, yet the proportion of the weakeſt light to the ſtrongeſt, by which the eye can conveniently ſee objects, perhaps does not exceed that of 1 to 10,000. How exquiſite are our faculties!

Experience ſhews, that objects appear ſo much more obſcure as they are more diſtant, and at laſt ceaſe to be viſible: this obſcurity ariſes from the paſſage of the rays of light through the air, a medium denſe and foul enough to obſtruct them in a very great degree, and diſſipate a prodigious quantity in the interval between the eye and the object. The experiments and calculation of M. Bouguer ſhew, that 100th part of the light is loſt at 189 fathoms of horizontal diſtance; that 7469 fathoms, or about 3¼ leagues, diſſipates one third of the light; and that they ceaſe at laſt to be viſible, becauſe the images by their diminution in ſize and light are incapable of making a ſufficient impreſſion on the eye.

By a calculation founded on experiment, M. Bouguer has ſhewn, that of 10,000 rays, that proceeding from a ſtar would reach our eye, if it were not for their paſſing through the atmoſphere, there reach it no more than are ſet down in the following table:

Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude.	Number of Rays.
0	5	8	2423	30	6613
1	47	9	2797	35	6963
2	192	10	3149	40	7237
3	454	11	3472	50	7624
4	802	12	3773	60	7866
5	1201	15	4551	70	8016
6	1616	20	5474	80	8098
7	2031	25	6136	90	8123

Mr. Bouguer has alſo ſhewn by experiment,

1. That the light of the ſun is about 300,000 times ſtronger than the light of the full moon, when at it's mean diſtance from the earth.

2. That the light of the ſun is not ſenſible when it is diminiſhed 1000,000,000,000 times, and of courſe that a body is truly opake when it permits only 1000,000,000,000 part of the ſun's light to paſs through it.

OF IMAGES AND FOCI.

On account of the extreme minuteneſs of the atoms of light it is clear, that a ſingle ray, or even a ſmall number of rays, cannot make a ſenſible impreſſion on the organ of ſight, of which the fibres are very coarſe when compared to the rays of light.

A great number of rays of light proceeding from the ſame point or portion of the ſurface of the body are neceſſary to render this portion viſible. But as the rays of light proceeding from the ſame point are wider from each other the farther they extend, it has been neceſſary for particular purpoſes either to bring them near and unite them together in a point, or to ſeparate them from each other.

We are able by the aſſiſtance of glaſſes to unite, in one ſenſible point, a great number of rays proceeding from the ſame point of an object; the rays thus united in a point form an image of that point of the object from which they proceed; this image is *brighter* in proportion as there are more rays united, and more *diſtinct* in proportion as the order in which they proceed, is better preſerved in their union. On placing a poliſhed and white plane at the place of their union, you will ſee this image painted in all it's proper colours, if no adventitious light is permitted to diſturb or render it confuſed.

The point of union of the rays of light formed by means of a glaſs lens, or a mirror, is called the *focus* of this glaſs or mirror. If this union is real, the focus is called a *real focus*, or ſimply *focus:* it is the place where the image of the object is formed, and proceeds to form another image in the eye, as if it were the real object. If this point of union is nothing more than a point, to which the rays in the new direction which has been given to them tend, but are not actually united, this point is called *an imaginary focus.* It is alſo the place where the *object appears really to be*, when ſeveral of the rays which have been diſperſed, enter in ſufficient quantity into the eye to form a ſenſible image of the object. For an object always appears to be in that place from whence it's light ſeems to come to our eye.

Since every ray carries with it the image of the object from whence it proceeds, it follows, *that if the rays, after having croſſed each other, and having formed an image at their interſection, are again united after either reflection or refraction, they will form a new image; and ſo on for ever, as long as their order is not confounded.* We may thus form images of the ſame object, as often as we can unite the proceeding rays without confounding them.

It follows, that ſo long as the progreſs only of the rays of light are attended to, the image may be conſidered as the object, and the object as the image; and even a ſecond image, as if the firſt had been the original object, &c.

The rays of light may be differently diſpoſed relatively to each other, and may be conſidered as *parallel, diverging,* or *converging.*

The rays are *parallel* when they always keep at the ſame diſtance from each other.

Thoſe rays which, in proceeding from a point, continually recede from each other, are called *diverging rays.*

Thoſe rays are named *converging,* which, proceeding from various parts, approach nearer to each other in their progreſs, having a tendency to unite in one point.

When two mediums touch each other, their ſurfaces muſt be either *plane,* or *convex,* or *concave;* and the rays which acting together paſs through theſe mediums, may be conſidered either as *parallel, converging,* or *diverging.* We will examine together the effects ariſing from theſe different circumſtances. In ſpeaking of convex or concave ſurfaces, I ſhall only conſider thoſe that are ſpherically ſuch.

OF REFRACTION AT A PLANE SURFACE.

Caſe I. *When incident parallel rays paſs obliquely from a rare into a denſe medium terminated by a plane ſurface.*

To perform the experiments for this and many other parts of optics, I uſe that part of the ſolar microſcope that carries the mirror, fixing it, as in the preſent inſtance, to a window ſhutter; on darkening the room, I can throw the ſolar rays into the room, and paſs them through the tube belonging to the microſcope; I can render them parallel, convergent, or divergent, according to the lens I adapt thereto.

The lens now in the tube makes the pencil proceeding therefrom cylindrical; this pencil, by turning the mirror, falls obliquely on the ſides of this box, (*fig.* 5, *pl.* 1,) whoſe ſides are of glaſs; each end has a circular aperture for occaſionally receiving a watch glaſs, which may be placed either with the convex or concave ſide outwards; the box is made water-tight, and is furniſhed with a cock for more eaſily emptying it of water.

The ray of light (at A, *fig.* 6, *pl.* 1,) entering the box filled with water, is refracted to B, and forms there upon this card, placed againſt the ſide of the box, a luminous circle, exactly the ſame ſize as that which entered the box (at A): on removing the card, and letting the ray of light proceed in the air, you ſee that it goes on in a direction exactly parallel to the incident ray, being of the ſame ſize through it's whole length.

The two pencils of light E A, E A, after being by refraction bent nearer the perpendiculars p p, p p, move on parallel to each other; and on being again refracted, and ſeparating from the perpendiculars s p, s p, you will find by meaſuring the diſtance between them that they ſtill retain their paralleliſm.

From hence it follows, that incident parallel rays paſſing obliquely from air into a maſs of water terminated by a plane ſurface, preſerve their paralleliſm in entering and going out of the water. The ſame is true of other mediums which differ in denſity,

ſity, but have only a moderate thickneſs, as in our preſent experiment.

This may be further illuſtrated by a diagram, *fig.* 4, *pl.* 1. Let A B C D be a ſolid piece of glaſs, with two parallel ſurfaces A B, C D, and let the incident ray E F be refracted into F G; then will F G be refracted by the ſecond ſurface into G H parallel to E F, or in the ſame direction as E F, becauſe the angle at F is equal to the angle of incidence at G; and therefore the angle of incidence at F will be equal to the angle of refraction at G.

Caſe 2. *When converging incident rays paſs from a rare into a denſe medium, and from this again into the ſame rare medium.*

For this experiment, I put into the tube a lens, ſomewhat more convex than that we uſed before; ſo that the pencil of light that iſſues from the tube is now in the form of a long cone, whoſe baſe is the lens.

I fill the box with water, and preſent it towards the light, ſo that the ſide A B, *fig.* 7, *plate* 1, may be perpendicular to the axis of the cone, and in ſuch manner that the point or extremity of the cone may reach the further ſide B C of the box.

I empty the box of it's water, and the cone of light becomes ſenſibly ſhorter, terminating as at E. By bringing the box nearer the window, ſo that the point of the cone may paſs beyond the further ſide, the cone is no longer of a regular ſhape, but as it appears at F G, and the point is removed ſomewhat further diſtant.

This experiment ſhews, that the rays of light do not converge ſo ſoon when they paſs from a rare medium into one more denſe; and that, on the contrary, they converge ſooner than they would otherwiſe do, when they paſs from a denſe into a rare medium. In other words, when converging rays go from a rare into a denſe medium, they become

come leſs convergent; but their convergence is increaſed in paſſing from a denſe into a rare medium.

Thus, *fig.* 18, *pl.* 1, the two converging incident rays *a d*, *b c*, which would meet at e, are bent towards the perpendicular by the refracting ſurface I H, and therefore proceed to E.

In the ſame manner the converging rays *l* g, *f* g, falling upon I H, are refracted to *h*, *h*, inſtead of going on and meeting at I: but on the contrary in proceeding from the refracting ſurface K L, the rays g *h*, g h, are refracted from the perpendicular, and therefore meet ſooner as at K, than they would otherwiſe have done: the rays are therefore twice bent, but in contrary directions, once at h, h, once at g, g.

Caſe 3. *When incident diverging rays enter into a denſe or rare medium.*

Every thing being diſpoſed as in the laſt experiment, I preſent the ſide of the box A D, *fig.* 8, *pl.* 1, when empty to the cone of light, ſo that it may coincide with the point of the cone G, which is where they begin to diverge, and will proceed on at B C, and form another cone directly oppoſed to the other, falling upon a white ſcreen, placed at about four inches from the further ſide of the box. I meaſure this cone, and then fill the box with water; the cone then becomes of an irregular ſhape; the baſe on the ſcreen is ſomewhat larger than it was before, but it is not ſo large at B C as it was before.

From hence we infer, that diverging rays become leſs diverging in paſſing from a rare into a denſe medium; and, on the contrary, that their divergence is increaſed by paſſing from a denſe into a rare medium.

Let us conſider the diagram, *fig.* 18, *pl.* 1, K h, K h, diverging rays meeting the refracting ſurface L K, do not proceed directly to G G, but are refracted, and approach the perpendicular, and go towards g and g, and are thus leſs divergent.

On the contrary, if they proceed from the denſe medium, they are refracted, and go towards l and f, which render them more diverging, being twice bent at h and g, and thus forming an irregular cone.

Hence the image of a ſmall object placed under water, is *one fourth nearer* to the ſurface than the object. And hence the bottom of a pond of water is ¼ *deeper* than it appears to a ſpectator above. An object at E, *fig.* 18, *pl.* 1, would appear at e. This may ſerve as a uſeful caution to thoſe among you, who are not ſwimmers, and prevent your plunging unwarily out of your depths.

If you immerſe a ſtick perpendicularly in water, until the immerſed part appears of an equal length with the part above; then meaſure the parts, and they will be found to be to one another about as 4 to 3.

Hence alſo a fiſh appears higher than it really is, and the markſman, in ſhooting at it, muſt make an allowance for this falſe appearance, or he will miſs his object.

If all the parts of an object, ſeen at ſome depth in the water, were equally diſplaced or altered, the image thereof would be exactly ſimilar to the object it repreſents; for the figure depends on the reſpective poſition of the parts, which is not changed by a motion common to the whole. But this is not the caſe, if the object under water be of any conſiderable ſize; for thoſe rays which come from the extremities that are moſt diſtant from the eye, fall more obliquely on the ſurface of the air, and are more refracted, and approach too near the refracting ſurface to preſerve a total conformity of the image with it's object. Thus an eye at *K*, *fig.* 18, *pl.* 1, viewing at the bottom of the water a ſtrait line, *g c d c g*, not only ſees the whole line nearer to the eye than it really is, but the extremities *g g* appear nearer than the other parts *d c*; thus it appears curved with the part towards the eye. Thus a ſtrait leaden pipe appears at the bottom of the water to be curved, and the bottom of a flat baſon deeper in the middle than at the ſides.

Very thick denſe mediums make objects appear larger than they really are; thus a fiſh appears larger in the water than when taken out, as do plants, ſtones, &c. To comprehend this, ſuppoſe for a moment, that *g*, *g*, *fig.* 18, *pl.* 1, are the extremities of an object ſeen at the bottom of the water; by the rays *g h*, *g h*. An eye placed in K judges of the ſize of the object by the angle G K G, larger than that of g K g; and the ſame happens with reſpect to every part of the object viewed through a denſer medium than air.

Hence it is, that objects in a different medium from that where the ſpectator is, generally appear ſomewhat diſtorted.

OF REFRACTION AT A CONVEX SURFACE.

1. *When parallel rays paſs out of a rarer into a denſer medium, whoſe ſurface is convex.*

Before we proceed to make any experiments, or reaſon upon them, I muſt obſerve to you, that lines drawn from the *center* of a ſpherical ſurface are always conſidered, by mathematicians, as *perpendiculars* to that ſurface, and the angles they make with the angles of incidence are the angles of inclination. So that as light paſſing into a denſer medium, is ſo refracted as to approach the perpendicular, or line drawn from the center of the ſpherical ſurface to the point of incidence; ſo in going from a denſe into a rare medium, the rays ſeparate from the ſame ſurface.

I place the glaſs box ſo that the pencil of light falls directly on the convex glaſs at the end, and you ſee that as ſoon as I pour water into the box, the rays converge, and meet in a point: ſo that parallel rays, in this caſe, are rendered convergent; a circumſtance that naturally ariſes from the laws of refraction, ſee *fig.* 9, *pl.* 1; for the parallel rays *h i*, *f g*, *fig.* 19, *pl.* 1, falling obliquely on the convex refracting ſurface, *g*, E, i, are bent towards the perpendiculars *i c*, or *g c*, (thoſe lines being the perpendiculars to the points of the convex ſurface, on which the two given rays fall), and tend to unite at the axis AB. You will alſo take notice, that thoſe rays which are furtheſt from the axis unite at points neareſt the refracting ſurface; thus the ray *h i* falls upon the axis at *k*; but the ray *d e* does not meet it, till it arrives at D; hence all thoſe which are not too diſtant from the axis, may be conſidered as uniting in one point.

2. *When converging rays, paſſing out of a rare medium, fall upon the ſurface of a denſer medium with a convex ſurface.*

I bring the box as before with the convex glaſs towards the ray of light; but in ſuch manner, that the converging point of the pencil ſhall fall exactly on the center A, (*fig.* 10, *pl.* 1,) of convexity. I pour water into the box, and you find that there is no change in the ſituation of this point, becauſe there is no obliquity of incidence.

Let us now try the effect with two other cones of light; one terminating at *b*, *fig.* 11, *pl.* 1, nearer the convex ſurface than it's center; the other being beyond the center of convexity at *c*, *fig.* 12, *pl.* 1: mark exactly the place where the cone terminates in each of theſe caſes, when there is no water in the box, and then fill it with water, and obſerve the difference in each caſe. You will find the firſt cone, *fig.* 11, (where the rays tended to unite at *b*, before they reached the center of convexity) lengthened, and the point thereof terminating at a greater diſtance B; but the cone, *fig.* 12, (where the rays tend to unite at a point *c*, beyond the center of the convex ſurface) is ſhortened, terminating at C.

Theſe experiments having made you maſters of the fact, I ſhall now conſider the three caſes in a diagram. It is evident, that if *converging* rays fall upon a convex ſurface, they either tend to unite at the center of the convexity; or 2dly, their point of union will be nearer the refracting ſurface than that center; or 3dly, it will be beyond that center.

In the firſt caſe, the rays do not deviate: thus the rays, *e f*, *d b*, *fig.* 20, *pl.* 1, converge at c, juſt as they would have done without the interpoſition of the refracting ſubſtance, becauſe they do not poſſeſs the property neceſſary for refraction, namely, obliquity of incidence. For the rays *e f*, *d b*, tending to c the center of the ſurface, may be conſidered as radii prolonged, and conſequently as perpendicular to the convex ſurface.

In the ſecond caſe, where the rays tend to unite nearer the ſurface than the center of convexity, they become leſs converging; for the ray, *i b*, *fig.* 20, *pl.* 1, which tends to k, is bent by the refracting ſurface, nearer the perpendicular d c, and is thus removed further from the ſurface, and joins the axis at o.

In the third caſe, where the rays tend to unite beyond the center of convexity, they become more converging: thus, the ray, *g b*, *fig.* 20, *pl.* 1, tending to *l*, further from the convex ſurface *b b f*, than c, by approaching the perpendicular *d c*, is brought nearer the center, and joins the axis at *p*, where it would be met by another ray, falling upon the ſurface with the ſame degree of obliquity, but from the other ſide of the axis. This is the more common of the three caſes.

3. *When diverging rays, paſſing out of a rare medium, fall upon a denſe one with a convex ſurface.*

To ſhew what happens with theſe rays, we have only, as before, to place the box ſo that the diverging rays may fall upon the convex ſurface, and to receive the light upon a plane ſurface in the box, and to mark the ſize of the luminous circle formed thereon, before we pour any water into the box. This being done, I ſhall now fill our box with water, and you will perceive, that the luminous circle is conſiderably ſmaller than it was before, *fig.* 13, *pl.* 1. If you remove the box further from the point, from which the diverging rays proceed, the baſe of the luminous cone will ſtill grow ſmaller, and at laſt become cylindrical; and if you go on removing it ſtill further, they will converge in a point.

From theſe experiments we draw the following concluſion, That diverging rays, in paſſing from a rare medium into a denſer with a convex ſurface, become leſs divergent, which may be carried ſo far, that they may become parallel, and even convergent.

The diverging rays *a m*, *a l*, *fig.* 21, *pl.* 1, meeting with the refracting ſurface *m b l*, do not proceed in ſtrait lines to *f* and *e*, but are refracted towards the perpendiculars *e* C, *c* C, which gives them the directions *m g*, *l h*, much leſs divergent.

If the rays that fall on the refracting ſurface, as *d m*, *i l*, are leſs diverging than the preceding, they will be refracted ſo as to converge at B.

Let us now ſuppoſe *the rays of light paſſing from a denſer medium into a rare one, the denſe medium being terminated by a convex ſurface on the ſide of the rare medium.*

Parallel

Parallel rays are thereby made to converge: thus the parallel rays *d e*, *g i*, *fig.* 12, *pl.* 2, falling on the refracting ſurface, *e i*, inſtead of proceeding to *f h*, are bent further from the perpendiculars *a* C, *b* C, ſo as to converge at *k*.

Converging rays become more converging: thus the rays *l e*, *n i*, which would, without refraction, go on towards *m* and *o*, are ſo refracted as to unite at *p*.

If the rays are diverging, the point from which they diverge is, 1ſt, either c, the center of convexity *e*, D, *i*; or 2dly, a point *r*, between the center and the convex ſurface; or 3dly, a point *q* beyond that center.

In the firſt caſe, the rays C *a*, C *b*, are not refracted, becauſe being radii they fall perpendicular to the convex ſurface.

In the ſecond caſe, where the rays *r e*, *r i* proceed from *r*, they do not go on toward *s* and *t*, but are refracted further from the perpendiculars *a* C, *b* C, and go on towards *x* and *y*, diverging more than before.

In the third caſe, the diverging rays *q e*, *q i*, become leſs diverging, and inſtead of proceeding towards *z* and *z*, they get cloſer together towards *g* and *h*, being refracted further from the perpendiculars *a* C, *b* C, and may be rendered parallel, or even convergent, according to the greater or leſs degree of divergence, when they arrive at the ſurface *e* D *i*.

OF REFRACTION AT A CONCAVE SURFACE.

1. *When parallel rays of light paſs from a rare medium into a denſe one, with a concave ſurface.*

One end of the box, *fig.* 5, *pl.* 1, is furniſhed with a glaſs with the concave ſurface outwards; this is now to be preſented towards the cones of light.

In the preſent inſtance, let parallel rays fall on the concave ſurface. Having obſerved the ſize of the luminous circle formed by them within the box, fill the box with water, and you will find that the pencil of light is enlarged, and the luminous circle is much increaſed. See *fig.* 14, *pl.* 1.

That parallel rays neceſſarily in this inſtance become diverging ones, may be alſo rendered clear by a diagram. For the parallel rays *a b* and *d e*, *fig.* 1, *pl.* 2, falling upon the concave refracting ſurface *e*, *b*, *b*, are by refraction made to approach the perpendicular *f* C, *g* C, which renders them diverging.

2. *When converging rays paſs from a rare medium into a denſe one, terminated with a concave ſurface.*

We proceed as in the foregoing experiment, obſerving where the converging rays terminate, before and after water is poured into the box, and that with different degrees of convergency.

You ſee, however great the convergency of the rays may be, that as ſoon as the water is put into the box, the cone is ſenſibly lengthened, *fig.* 15, *pl.* 1. With a leſs degree of convergence they are ſenſibly ſeparated from each other; ſo that by altering the degree of convergency we render them either parallel or diverging. To view this in a diagram, you may conſider the rays *a b*, *d e*, *fig.* 3, *pl.* 2, tending to converge at O; theſe are by refraction made to approach the perpendiculars *f* C and *g* C, and thus do not unite till they come to *i*.

3. *When diverging rays paſs from a rare medium into a denſe one, terminated by a concave ſurface.*

Every thing being diſpoſed as in the laſt experiment, remove the box ſo that the point where the rays meet, or croſs, and begin to diverge, may fall upon the center of the concave glaſs; receive the baſe of this cone on a plane placed at about ſeven or eight inches from the glaſs, meaſure the diameter, and fill the box with water.

Repeat the experiment with the concave glaſs nearer C, *fig.* 16, *pl.* 1, and afterwards further from it.

In the firſt caſe, the ſize of the circle is not enlarged, nor the cone of light altered. In the ſecond, the baſe of the cone is ſmaller in the water than it was in the air. In the third, it is ſomewhat enlarged. See *fig.* 16 and 17, *pl.* 1.

In the firſt caſe, the rays undergo no alteration, becauſe they have no obliquity of incidence, for C*b* and C*e*, *fig.* 4, *pl.* 2, are radii of the concavity, and continue their rout to *f* and *g*, as they would have done without the interpoſition of a refracting medium.

In the ſecond, they become leſs divergent, for the two diverging rays *k b* and *k e*, inſtead of going to *d* and *h*, proceed to *a* and *e*, the refraction making them approach the perpendiculars *f* C, *g* C.

In the third caſe, which is the moſt general, the rays become more diverging; for *l b* and *l e*, which tend towards *m* and *n*, are turned out of their way towards *i* and *o*, by approaching the perpendiculars *f* C and *g* C, and thereby become more diverging than they were before.

Let us now ſuppoſe that the rays of light paſs from a denſe medium into a rare one, and that the denſe medium is terminated on the emergent ſide by a concave ſurface.

The parallel rays become divergent, for the parallel rays *d e*, *g i*, *fig.* 22, *pl.* 1, in emerging from the concave ſurface *e* D *i*, do not continue their rout in ſtrait lines towards *f* and *h*, but are carried towards *m* and *p*, by ſeparating from the perpendiculars C *a*, C *b*, which renders them divergent.

If the rays are converging, they may be divided into three caſes. 1. When the point of convergency tends preciſely to the center C, of the concavity *e* D *i*; in this the rays *a e*, *b i*, do not ſuffer any refraction; becauſe being the continuation of the radii C *e*, C *i*, of the concavity *e* D *i*, there is no point of oblique incidence.

2. When the rays *q e*, *r i*, tend to converge to the point *n*, nearer the concave ſurface *e* D *i* than it's center C, by ſeparating from the perpendiculars C *e*, C *i*, they unite at o, and are thus rendered more converging.

3. When they tend to a point *l*, which is further from the concave ſurface than the center of curvature, they are rendered leſs convergent. For the rays *ſ e*, *t i*, which tend naturally to converge to the point *l*, by ſeparating from the perpendiculars C *e*, C *c*, unite in *k*, further off than they would have done without refraction, if they were only a little converging; on arriving at the concave ſurface *e* D *i*, the refraction may render them parallel or diverging.

The diverging rays E *e*, E *i*, diverging from the point E, which without the change from the medium would go on towards *u* and *x*, but by the refraction ſeparating from the perpendiculars C *e*, C *i*, they are turned towards *y* and *z*, diverging more than before.

OF GLASS LENSES.

By a lens opticians mean a tranſparent body of a different denſity from the ſurrounding medium, and terminated by two ſurfaces, either both ſpherical, or one plane and the other ſpherical. And as the lenſes for optical uſes are generally made of glaſs, it is uſual to call them *glaſſes*, with the addition of the uſe they are intended for; as a *magni-*

fying glaſs, a *ſpectacle glaſs*, *an object or eye glaſs of a teleſcope*, &c.

Glaſs was probably the invention of ſome manufacturer, having nothing elſe in view but raiſing a fortune by his new manufacture: but from hence we are ſupplied with teleſcopes, microſcopes, and priſms, which let us into ſecrets of nature unſuſpected before, open to us the immeaſurable grandeur of the univerſe, and bring us acquainted with animals to whom a ſpoonful of vinegar ſerves for a habitable world; thereby raiſing our idea of the *Author of nature*, by diſplaying the magnificence and wonders of his works. From hence likewiſe has proceeded gradually a more exact knowledge of the laws of attraction, the velocity of light, the exiſtence of ether, and the extreme rarity of bodies. Thus the unlearned are often made to lend a helping hand to the contemplative in the proſecution of his ſcience; and the man of this world inſtrumental in opening a larger field to our theology. Inventions are often termed *accidental*, and ſo indeed they are with reſpect to us; but *accidents* ariſe from certain cauſes which produce them, when it is proper they ſhould be manifeſted, and are therefore to be referred to the *diſpoſer* of all events.

A lens having one ſide plane and the other convex, is called a *plano-convex*; where one ſide is plane and the other concave, it is a *plano-concave*. A lens terminated by two convex ſides, is called *a double convex*; *a double concave*, if terminated by two concave ſides. A lens having one ſide concave, the other convex, is called *a concavo-convex lens*. See *fig.* 9, *pl.* 2:

From theſe definitions you will readily conceive, that there may be an infinite variety in the degrees of convexity and concavity; for a convex ſurface may be conſidered as forming part of a

ſphere;

ſphere; and as the radius or diameter of this ſphere is greater or leſs, the convexity will be different.

Hence when I ſay that the radius of the convex ſurface of a glaſs is three inches, I mean that it is the portion of a ſphere whoſe radius is three inches. To render this ſubject clearer, here are a variety of lenſes of different convexities; from theſe you ſee, that the ſmaller the radius is, the more the ſurface is curved, or the greater is it's deviation from a ſtrait line. On the contrary, the longer the radius the more it approaches to a plane; ſo that a plane ſurface may be conſidered as a convex ſurface of an infinite radius.

To explain the effect produced in the appearance of objects, by convex and concave lenſes, we muſt diſtinguiſh two caſes: 1. Where the object is at a conſiderable diſtance from the lens. 2. Where the object is near the lens. Before, however, I enter upon this explanation, it will be neceſſary to define what is meant by the AXIS *of a lens*. A ſtrait line drawn perpendicular to both the ſides of any lens is called the axis thereof;* the axis therefore paſſes through the center of the ſpherical ſides; and as we repreſent the two ſurfaces by arches of a circle, you have only to draw a line through their reſpective centers, and it will repreſent the axis of the lens. Thus the center of the arch A E B, *fig.* 23, *pl.* 2, is at C, that of A F B at D, and the line C D is the axis of this lens; it is eaſy to ſee that the axis paſſes through the middle, and that no lens excepting a ſphere can have more than one axis, becauſe no other line can paſs through the two centers C, D; and therefore all pencils are conſidered as oblique, excepting thoſe whoſe foci are in the axis of the lens.

As

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[*] If one of the ſurfaces be plane, the axis of the lens falls perpendicular upon the plane ſurface, and proceeds through the center of the ſpherical one.

As the axis is perpendicular to the two ſurfaces, it is plain from the nature of refraction, that a ray of light paſſing in this direction is not refracted, but goes on in the ſame direction in which it entered.

No ray that paſſes through the center o, *fig.* 23, *pl.* 1, of a lens is refracted; for the two tangents at E and F are parallel, and the effect is therefore the ſame as if the ray paſſed through a piece of glaſs whoſe ſides are parallel.

I ſhall now proceed to conſider the nature of double convex lenſes. It is the property of theſe to make parallel rays converge to a focus; to increaſe the convergence of converging rays; to diminiſh the divergence of diverging rays, and that ſo much under certain circumſtances as to render them parallel or convergent.

Let us conſider A B, *fig.* 24, *pl.* 1, as a convex lens, whoſe axis is the line O E F P; and let us ſuppoſe that on this axis, and at a great diſtance from the glaſs, there is a luminous point or object O diffuſing it's rays in all directions; ſome of theſe, as O M, O E, and O N, will fall upon the glaſs, the middle one O E will not be refracted, but paſs on in the direction E F P. The two other rays will be refracted and bent both at entering and going out, ſo as to meet at J ſomewhere on the axis, and then go on in the direction J Q and J R: the other rays between M and N, will be ſo refracted as to unite on the axis at the ſame point J. Thus the rays O M and O N, and thoſe between them, which without the interpoſition of the glaſs would have followed their reſpective rectilinear directions, are ſo bent thereby as to follow other directions, and proceed as if they came from the point J; and an eye placed at P would be affected in the ſame manner as if the luminous point was at J; the glaſs A B forming an object at J, exactly repreſenting the object at O. Thus a conſiderable change is produced by the lens; a diſtant object, as O, is as it were tranſplanted and brought ſuddenly to J.

Let us now conſider the effect produced on the rays of light, when the object is very diſtant from the lens. In *fig.* 13, *pl.* 2, M N repreſents a convex lens, O A B T S the axis of the lens, O P a diſtant object ſituated on the axis; every point of this object diffuſes rays in all directions; of theſe we are only concerned with thoſe that fall upon the lens; and to render the ſubject clearer, I ſhall only conſider three rays O A, O M, O N, proceeding from the point O; of theſe the firſt O A paſſing through the middle of the lens, it's direction is not altered, but continues after it has paſſed through to go on in the line B T S, the axis of the glaſs. But the other two, O M, O N, are ſo refracted both at entering and quitting the lens, that they unite at T on the axis, from whence they again proceed in the directions M T Q, N T R, ſo that if an eye were to meet with them, they would produce the ſame effect thereon as if the object O had been ſituated at T. To diſtinguiſh, however, the true point O from the point T, the firſt is called the *object*, the other the *image* of that object, which image in it's turn becomes alſo an object. When the object is at a conſiderable diſtance, the point T is conſidered as the *focus* of the glaſs. The following remarks on this point are neceſſary to be conſidered with attention.

1. When the point O, or the object, is at an infinite diſtance, the rays O M, O A, O N, may be conſidered as parallel to each other, and to the axis of the lens.

2. The focal point T, is a point behind the glaſs, where parallel rays falling upon that glaſs are united by the refractive power of the lens.

3. The focus of a lens, and the place where the image of an object ſituated in the axis of the lens, but at an infinite diſtance from the lens, is repreſented, are the ſame thing.

4. The diſtance of the point T from the lens is termed the focal *diſtance.*

5. Every convex lens has a particular focus; in ſome it is greater, in others leſs, which is eaſily found by expoſing the glaſs to the ſun, and obſerving where the rays unite.

6. Thoſe lenſes which are formed by the arcs of ſmall circles, have their foci very cloſe to them, and the focal point is further off in proportion as the ſurface or ſides of the lens is formed by arcs of a longer radius.

7. In order to form a proper idea of the optical effect of any lens, it is neceſſary to know it's focal diſtance.

8. When parallel rays A B, C D, *pl.* 3, *fig.* 4, fall upon a plano-convex lens D e R, and paſs through it, they will be ſo refracted, as to unite at a point F behind it; this point is called the *principal focus*, and it's diſtance F e from the middle of the glaſs it's *focal* diſtance, which is equal to *twice the radius*, or the diameter of the ſphere's convexity.

9. When parallel rays A B, C D, *fig.* 5, *pl.* 3, fall upon a glaſs D e B equally convex on both ſides, and paſs through it, they will be ſo refracted as to unite in a point or *principal focus* F, whoſe diſtance is equal to the *radius* or ſemidiameter of the ſphere of the glaſs's convexity.

The rays all croſs the middle ray *d* e in the focus F, and then diverge from it to the contrary ſides, in the ſame manner as they converged in coming thereto. See *fig.* 4 and 5, *pl.* 3.

If another double convex lens h g, *fig.* 5, *pl.* 3, be placed in the rays at the ſame diſtance from the focus, they will be ſo refracted thereby as to proceed from it in a parallel direction, as at b h, g e, going on in the ſame manner as when they fell upon the firſt glaſs; but on contrary ſides of the middle ray D e F f f, for the ray A B F will go on in the direction F h b, and the ray C D F in the direction F g e, and ſo of the reſt.

To render the progreſs of the rays from an object through a lens, to the image behind, more evident, I have conſtructed a model in which the rays are repreſented by ſilk ſtrings; that it may be more clear, the rays iſſue on from three points, and only three rays from each of theſe points.

In *fig.* 9, *pl.* 4, we have a figure of this model. A B C is the object placed ſomewhat beyond the focus of the convex lens d e f. The rays A *d*, A *e*, A *f*, flowing from the point A, are refracted into the directions *d a*, *e a*, *f a*, meeting in the point *a*. The rays B *d*, B *e*, B *f*, proceeding from B, paſs through the glaſs, and are ſo refracted as to unite at *b*. In the ſame manner thoſe that flow from the point c, are conveyed and meet at *c*; at each of the points *a*, *b*, *c*, an image is formed of the reſpective points A, B, C. The ſame takes place with all the other intermediate points, by which means a perfect image of the object is formed.

I have already obſerved to you, that an object at an infinite diſtance has it's image formed at the focus of a convex lens, provided the object be ſituated on the axis of the lens. I ſhall now proceed to conſider nearer objects, but ſtill ſituated in the axis; and you will find the nearer the object approaches the glaſs, the further the image is removed therefrom.

Thus let us ſuppoſe that F, *fig.* 11, *pl.* 2, be the focus of the lens M M, or place where the image of a diſtant object is repreſented. If the object be brought ſucceſſively to P, Q, and R, the image will be ſucceſſively removed further from the glaſs to p, q, and r; the diſtance, b r, &c. of the image always correſponding to that of the object A P, &c. Mathematicians have rules for calculating theſe diſtances, which would lead us too far into the intricacies of the ſcience; it will be therefore ſufficient to obſerve in general, that the more we diminiſh the diſtance of an object from the lens, the more that of the image is increaſed, which will be rendered plainer by an example, ſuppoſe of a lens of ſix inch focus; that is, if the object is at an infinite diſtance, the focus will be preciſely at ſix inches; but when the object approaches the lens, the diſtance of the image will increaſe, as in the following table:

Diſtance of the object.	*Diſtance of the image.*
Infinite	6 inches
42	7
24	8
18	9
15	10
12	12
10	15
9	18
8	24
7	42
6	Infinite.

Although theſe numbers only agree with a lens of 6 inches focus, yet we may deduce the following conſequences from them:

1. If the object be at an infinite diſtance, the image will be at the focus.

2. If the object be at double the diſtance of the focus from the glaſs, the image will alſo be at double the diſtance of the focus from the glaſs; thus in the foregoing example, when the object was at twice 6 or 12, the image was alſo at 12 inches.

3. When the object is at the ſame diſtance

from the glaſs as the focus, the image is removed to an infinite diſtance on the oppoſite ſide.

4. In general the diſtance of the object and the image correſpond reciprocally to each other; ſo that if the object be placed where the image was ſituated, the image will be found where the object was before placed.

5. If the lens AB collect in J, *fig.* 24, *pl.* 1, the rays which emane from the point O, it will alſo collect the rays from the point J, and conſequently the rays may be returned back in the direction in which they proceeded. This article is of conſiderable importance towards a thorough knowledge of the nature of lenſes; thus for example, when I know that a lens has repreſented, at eight inches from it, the image of an object which is at 24 inches on the oppoſite ſide, I may conclude, that if the object be at eight inches, the image will be at 24.

When the object is ſituated at the focal diſtance from the glaſs, the image is ſuddenly removed to an infinite diſtance therefrom.

You inquire of me, what then becomes of the image, when the object is within the focal diſtance? can it be removed to a diſtance greater than infinite? this is impoſſible. The queſtion, though not eaſily reſolvable by metaphyſics, does not embarraſs a mathematician; for he proves that the image in this caſe paſſes to the other ſide of the glaſs, and is found of the ſame ſide with the object.

In every repreſentation formed by lenſes, there are two circumſtances to attend to, one concerning the *place* where the image is formed, the other the *ſize* of the image. Having explained the firſt, I now proceed to conſider the ſecond. Let O P, *fig.* 14, *pl.* 2, be an object ſituated on the axis of the convex lens M N; find firſt the point I, where the rays proceeding from O, meet the axis; this done, we have to find where the other point P will be repreſented.

To do this, conſider the rays P M, P A, P N, which proceeding from P fall on the lens, and you ſee that the direction of the ray P A is not altered, becauſe it falls upon the middle of the glaſs, but continues to proceed in the line A K S; it will therefore be ſomewhere in this line, as at K, that the rays P M, P N, will meet, and K will be the image of the other end of the object, the point K being determined by the place where a perpendicular to J O, from J, meets the line P S, and I K will be the image of the object. It is evident from this, that the image is *inverted*; ſo that if Q R was horizontal, and the object O P a man, in the image the feet would be upwards and the head downwards. It is alſo clear,

1. That the image is always ſmall in proportion as it is nearer the lens, and larger the further it is removed therefrom. Thus O P, *fig.* 15, *pl.* 2, being the object, and M M the lens, the image will be ſmaller if formed at Q, than if it were formed at R, S, or T; that is, the image is larger the further it is from the lens.

2. There is a caſe where the image is preciſely at the ſame diſtance from the lens as the object, which is when the object is placed at twice the focal diſtance from the lens.

3. When the image is twice as far from the glaſs as the object, it becomes double the ſize of the object, and in general the image is ſo many times larger than the object, as it exceeds it in diſtance from the lens: now the nearer the object is to the glaſs, the more the image is removed from it, and is conſequently ſo much larger.

4. On the contrary, ſo much as the image is nearer to the glaſs than the object, it is ſo many times ſmaller than the object. If then the diſtance of the image from the glaſs was 1000 times leſs than that of the object, it would alſo be 1000 times ſmaller.

OF BURNING-GLASSES.

The ſun, as we all experience, is the cauſe of heat at the ſurface of the earth; it's effects are moſt violent in thoſe regions where it's rays fall with the leaſt obliquity, for they arrive there with greater force, and in a greater quantity. Winds meet and deſtroy each other's forces, but the rays of the ſun travel onward without impeding each other in their progreſs.

All ſubſtances feel the influences of the ſolar rays, not only in proportion as they ſtrike againſt them more or leſs directly, but according alſo as they are fitted for their reception. For the rays, though they continue ever to operate, are reſtrained from acting too fiercely, by the nature and diſpoſition of the bodies on which they fall, and their own equable diffuſion. To give the rays greater power, they muſt be collected by art; and when their action is concentrated, they conſume or change all bodies with inexpreſſible force.

One of the firſt uſes to which convex lenſes were applied, was that of collecting the rays of the ſun, in order to ſet wood or other combuſtible matter on fire.

The ſun is ſo far off, that we may conſider every point upon it's ſurface as at an infinite diſtance, and may therefore ſuppoſe the rays emitted from each point to be parallel to each other; conſequently all the rays from the ſun that fall upon a convex lens, will by paſſing through the glaſs be made to converge, and unite in a focus behind it.

The *effect* of the rays of the ſun, when they are thus collected, is the reaſon why the point where they are collected is called the *focus:* and the name, after it had for this reaſon been given to this point, has been made uſe of as a general one to ſtand for any point, where converging rays meet, or to which they tend.

Every lens, whether convex, or plano-convex, will collect by refraction the rays of the ſun diſperſed over it's ſurface into a point, and thus become a burning lens. To underſtand this, let M N, *fig.* 15, *pl.* 2, repreſent a convex lens, receiving on it's ſurface the rays R, R, R, of the ſun; theſe are refracted by the lens into a ſmall luminous circle, which is the image of the ſun.

As all the rays which fall upon the lens are united in it's focus, their effect ought to be ſo much more, as the ſurface of the lens exceeds that of the focus. Thus if a lens four inches broad collect the ſun's rays into a focus at the diſtance of one foot or twelve inches, the image will not be more than 1-10th of an inch broad. The ſurface of this little circle is 1600 times leſs than the ſurface of the lens, and conſequently the ſun's light muſt be ſo many times denſer within that circle; it is not therefore ſurprizing that it burns with a degree of ardour and violence exceeding any culinary fire.

That the ancients made uſe of burning-glaſſes, is evident from a paſſage in a play of *Ariſtophanes*, called the Clouds, where *Strepſiades* tells *Socrates*, that he had found out an excellent method to defeat his creditors, if they ſhould bring an action againſt him. His contrivance was, that he would get from the jewellers a certain tranſparent ſtone, that was uſed for kindling fire, and then ſtanding at a diſtance, he would hold it to the ſun, and melt down the wax on which the action was written.

The moſt conſiderable of theſe glaſſes are thoſe that were made by M. Tſchirnhauſen and

Mr. Parker. Tho' I have already mentioned * both to you, it may be worth while to enter into ſomewhat a larger detail of their effects. The diameter of that of M. Tſchirnhauſen was three feet, the focus was formed at twelve feet, and it's diameter 1½ inch and weighed 160 pounds. To render the focus more vivid, it was collected a ſecond time, by a lens placed parallel to the firſt, and ſo ſituated, that the diameter of the cone of rays, formed by the firſt lens, was exactly equal to the diameter of the ſecond lens; ſo that it received all the rays, and the focus was contracted to eight lines, and it's force was increaſed proportionably.

The lens made by Mr. Parker, of Fleet-ſtreet, was formed of flint glaſs, is three feet in diameter, and when fixed in it's frame, expoſes a clear ſurface of 2 feet 8 ½ inches in diameter, weighs 212 pounds, focal length 6 feet 8 inches, diameter of the focus 1 inch. A ſecond lens was uſed, which reduced the focus to half an inch.

I ſhall now recite ſome of the principal effects of that made by M. Tſchirnhauſen, having already noticed thoſe of Mr. Parker's.

1. Every kind of wood catched fire in an inſtant, whether hard or green, or ſoaked in water.

2. Thin iron plates grew red-hot in a moment, and then melted.

3. Tiles, ſlates, and all manner of earth, grew red in a moment, and vitrified.

4. Sulphur, pitch, and all reſinous bodies, melted under water.

5. Fir wood expoſed to the focus under water, did not ſeem changed; but when broken, the inſide was found burnt to a coal.

6. If a cavity was made in a piece of charcoal, and the ſubſtances to be acted upon were put in it, the effect of the lens was much increaſed.

7. Any metal whatſoever thus incloſed in the

cavity

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* Vol. i. p. 389.

cavity of a piece of charcoal, melted in a moment, the fire ſparkling like that of a forge.

8. The aſhes of wood, paper, linen, and all vegetable ſubſtances, were turned, in a moment, into a tranſparent glaſs.

9. The ſubſtances moſt difficult to be wrought on were thoſe of a white colour.

10. All metals vitrified on a china plate, when the china plate was ſo thick as not to melt, and the heat was gradually communicated.

11. When copper was thus melted, and thrown quickly into cold water, it produced ſo violent a ſhock, as broke the ſtrongeſt earthen veſſels, and the copper was entirely diſſipated.*

The experiments with a burning-glaſs, among other things, prove that fire is regularly diffuſed through all ſpace, and perfect therein; and that when properly directed and put in action, it burns with a vehemence ſuperior to any culinary fire. The fire was in the expanſe before the glaſs was applied; and the ſurface by which it was collected and directed, only put that fire into action, which already exiſted.

Mr. Parker obſerved a violent *rotatory* motion in the rays at the focus, which rotatory motion became viſible on a ſmall maſs of *gold* when melted; for it inſtantly aſſumed a motion round it's axis, and that invariably *the ſame way as the earth moves* round it's axis. The velocity of this motion was accelerated, if at any time the ſun ſhone with greater brightneſs than before.

Though the heat of the focus was ſo intenſe as to flux gold in a few ſeconds, yet there was no heat at a ſmall diſtance therefrom; and the finger might be placed in the cone of rays, within an inch of the focus, without receiving any hurt. Mr. Parker had the curioſity to try what the ſenſation of burning at the focus was, and having put his finger there for that purpoſe, he ſays, it neither ſeemed like the burning of a fire, nor a candle, but the ſenſation was that of a *ſharp cut* with a lancet.

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* When plates of copper are caſt at a foundry, after the moulds have been well heated and dried, they wrap them round with blankets to prevent the acceſs of any moiſture, which would not only diſſipate the metal, but blow up the works, and even overturn the houſe itſelf.

You may, by means of the focal rays from this glaſs, char or burn a piece of wood to a coal in a decanter of water, and yet the ſides of the decanter, through which the rays paſs ſo very near the focus, will not be cracked, nor any ways affected; nor will the water be in the leaſt degree warmed. The wood was afterwards taken out, and the rays thrown on the water; but no continuance of collected rays in this way, would either heat the water, or crack the glaſs; but if a piece of metal be put into the water, it ſoon becomes too hot to be touched, and communicating it's heat to the water, makes it not only warm, but ſometimes cauſes it to boil.

Though the water alone is not affected; yet when a little ink was poured into it, the water began to boil in a very little time.

OF THE SCIOPTRIC BALL, OR CAMERA OBSCURA.

By *camera obſcura*, opticians mean any darkened room, out of which all the light is excluded, but what comes through a lens upon a white ſcreen properly placed, on which the objects ſeen without are depicted.

It is in general made in two different ways: one is, a large room or chamber, made as dark as poſſible, with the ſcioptric ball fixed in the window-ſhutter: the other is ſmall, and made in various ways, as that of a box, a book, &c. for the conveniency of carrying it from place to place; whence it is called the *portable* camera obſcura, and is uſeful to a young artiſt in taking the optical view of any propoſed proſpect.

It is by means of convex lenſes that we obtain all the advantages that are derived from the camera obſcura, which exhibits, in a moſt pleaſing manner, all the objects ſeen without in their natural proportions, colours, and motions, more ~~as~~ vivid and beautiful than ~~as~~ life; which I ſhall ſhew you as ſoon as I have explained the nature of the inſtrument.

Let W, X, Y, Z, *fig.* 6, *pl.* 2, repreſent a darkened room or box, well cloſed on all ſides, ſo as to admit no light but what comes through the lens o, whoſe focus is ſuch that the image of the objects from without fall exactly on the wall.

In the diagram, to prevent confuſion from too many lines, only three pencils are drawn, one from each of the extremes P, R, the other from the middle Q, of the object P Q R; and in theſe pencils there are only drawn the axis, and the two extreme rays.

But the rays that flow from any point (as P, for inſtance) upon the lens are innumerable, the whole conical ſpace b P d being filled with them. Theſe are all collected and united at the focus p, and there received upon the white paper, and are reflected by it in all manner of directions; ſo that to a ſpectator in the room, p is now, as it were, a real object, exactly ſimilar to the phyſical point P, in proportion to it, as O p to O P, and p is of the ſame colour with P, becauſe the rays flowing upon the lens from P are united at p, diſtinct and ſeparate from the rays coming from other parts of the object.

Every other phyſical point of the object ſends forth it's cone of rays, which are united by the lens, orderly at p, q, r, and being there reflected by the ſcreen, the image of the whole object is diſtinct and viſible, like a picture drawn upon canvas; but much more lively and diſtinct than the beſt finiſhed drawings of the greateſt artiſt.

If the objects are very remote in proportion to the focal length of the lens, we ſhall have the pictures of thoſe that are in the ſame neighbourhood, pretty diſtinct at the ſame time, though they are at the ſame diſtances from the lens; becauſe in that caſe, the focal diſtances of the refracted rays differ only inſenſibly.

There will be as many foci upon the paper as there are radiant points in the object, from which the rays proceed; and theſe foci will be diſpoſed in the ſame manner, in reſpect of one another, as the radiants. Thoſe foci will be the moſt bright in which the moſt rays are united, and thoſe will be the leaſt bright in which the feweſt rays are united.

Now the moſt rays will be united in thoſe foci, which correſpond to the radiants, from which the moſt light proceeds; and the feweſt will be collected in thoſe focal points, that correſpond to radiants from which the leaſt light proceeds. Therefore the light and ſhade upon the paper will be anſwerable to the light and ſhade upon the ſurface of the object.

When the rays from theſe foci are reflected by the paper, and enter the eye of a ſpectator, who looks at the paper, he will there ſee the picture, or likeneſs of that object; for the figure made up of theſe foci, will be like the figure of the object, becauſe the focal points are diſpoſed in the ſame manner, with reſpect to one another, that the radiants in the objects are. The light and ſhade upon the paper are every where anſwerable to the

light

light and ſhade upon the ſurface of the object. And the colouring of each particular part through the whole figure upon the paper, is the ſame with the colouring of the correſpondent part in the object.

If the ſcreen be moved nearer the lens, as to x, or farther from it, as to y, the picture will be confuſed, becauſe the rays proceeding from the next adjacent objects begin to interfere and mix together, as the rays from *a* will be mixed with thoſe from P. The diſtinctneſs of the picture, we have obſerved, is entirely owing to the ſeparation of the rays belonging to every point of the object upon their reception on the ſcreen. If the ſcreen be removed farther and farther from the focus, the picture will become more and more indiſtinct, and at length totally vaniſh, no one part being diſtinguiſhable from the reſt; for all the rays, that proceed from the ſeveral points, muſt go to as many correſpondent points to make a complete image of the object. *The brightneſs of the picture, when it's diſtance from the lens is given, is in proportion to the area of the lens.* The diſtinctneſs of the picture is not the ſame thing as it's brightneſs; nor is the confuſion of parts the ſame thing as it's obſcurity.

The picture may be diſtinct in all it's parts; the rays which come from one and the ſame point of the object, may be exactly collected into one and the ſame point on the paper; and yet, if but few rays ſhould paſs through the lens, the picture will be diſtinct, though faintly enlightened. Or, though the picture be confuſed, either by the ſcreen being placed at an improper diſtance from the lens, or from any other cauſe, yet, if many rays paſs through the lens, the picture will be a bright one, notwithſtanding it's confuſion.

Hence you ſee that the brightneſs of the picture in every part depends on the rays that come to that part, and that the picture will be bright or faint, in proportion as it is formed by more or fewer rays. Now the quantity of light, or number of rays that paſs from any given object into the room, is greater or ſmaller in proportion as the hole through which they paſs is greater or leſs, or as the area of the lens is greater or ſmaller.

The foot of the croſs will be at r, and the top at p, for every object muſt be repreſented at the place where a line falls, drawn from the object through the middle of the lens; and conſequently what is at the top will be repreſented at the bottom; objects to the right will be the left in the picture.

Why the image is inverted, is evident from a bare inſpection of the figure; and it is alſo evident, that this inverſion is not owing abſolutely to the lens; for if that be removed, and the light be admitted through a ſmall hole in the ſhutter, as you ſaw at the beginning of this Lecture, we ſhall have an inverted picture on the ſcreen, though very imperfect when compared to that formed with the lens: the ſeveral pencils in both caſes croſs each other; but without the lens, the picture is very faint and confuſed; it is faint for want of ſufficient light, ſo many rays from each point not being collected together; it is confuſed becauſe the rays that proceed from the adjacent objects interfere and mingle together.

Let us now proceed to try the *ſcioptric ball*, or ox's eye. To uſe this, the windows of the room muſt be made to ſhut very cloſe, and if there be any crevices they ſhould be ſtopped, as we have done here, by nailing ſlips of cloth cloſe over them; the ſaſh is thrown up, and we have cut a hole in the ſhutter ſufficient to let the ball move freely therein: to this we ſhall ſcrew our inſtrument, which conſiſts of three parts, a frame, a ball, and a lens. The flat ſide of the frame is to be placed cloſe to the window ſhutter; the frame conſiſts of two parts, the flat board with a hole in it, and a ſcrew, to which a ring may be ſcrewed, by which the ball is confined; it moves with more or leſs eaſe, as this ring is ſcrewed more or leſs tightly; the ball has a large cylindrical hole at each end, which is cut to a female ſcrew for receiving a lens fitted in a cell. By the motion of the ball, the axis of the lens may be turned different ways; and the ſphericity of the frame and ball prevents any light being tranſmitted between them. There are uſually two lenſes of different focal lengths; by uſing both together you obtain a third, having a ſhorter focus than either of the others. There is a paper ſcreen, and a half poliſhed glaſs, with proper ſupports, ſo that I may place either of them exactly in the focus, by moving them to and fro till the picture is diſtinct.

This inſtrument may be conſidered as a kind of *artificial eye;* the frame may repreſent a fruſtrum of the orbit of the eye, and the wooden ball which is moveable every way therein the globe of the eye, moveable every way in it's orbit; the hole in the ball repreſents the pupil of the eye, the convex lens correſponds to the cryſtalline humour, and the ſcreen to the retina; all which you will better comprehend when we come to explain the nature of viſion. I fix the ſcioptric ball in it's place, and darken the room, and ſet the ſcreen at a proper diſtance from the lens.

You ſee what a beautiful and lively picture of all the objects before the window is exhibited on the ſcreen. It may with propriety be termed nature's art of painting. You have perſpective here in perfection, or a juſt diminution of objects in proportion to the diſtances, the images being all in proportion to the reſpective apparent magnitudes of the objects ſeen by an eye at the hole in the window. The colouring here is juſt and natural, the lights and ſhades perfectly juſt, and the motions of all objects are perfectly expreſſed; the leaves quiver, the boughs wave, the birds fly, &c. as in nature, though much quicker, and in a leſſer ſcene. From the camera obſcura, the painter may learn his imperfections; he may ſee what he ſhould do, and know what he cannot perform.

OBSERVATIONS ON THE SCIOPTRIC BALL.

All other circumſtances being the ſame, the pictures of objects that are near, as within 5, 10, or 20 yards, are more vivid than thoſe that are more remote. Univerſally, the pictures will be more diſtinct and pleaſant, when the objects are at ſuch moderate diſtances, in proportion to the focal length of the lens, as to exhibit ſmall parts, as the features of a perſon's face, the tiles of a houſe, &c. If the light without is favourable, and the ſpectator has been ſome time in the dark, it is ſurpriſing how diſtinct and bold objects will appear, that are diminiſhed at leaſt 20 or 30 times; and a perſon may be known, when his features are no bigger than in that proportion. The lights and tints are then exquiſitely delicate and perfectly juſt, and the relievos of objects ſurprizingly bold. A diſtant proſpect appears perfect enough, but does not form ſo entertaining a picture.

All light ſhould be excluded from it but what comes through the lens; for in proportion as the field about is darker, the objects will appear brighter, as the ſtars do in a dark night. The ſpectator himſelf ſhould alſo be in the dark, at leaſt while he looks at the picture; for by this means the pupils of his eyes enlarge; and as they enlarge, the apparent brightneſs of the picture will increaſe; and being free from extraneous light, the impreſſions on the retina will be more vivid and ſenſible. The objects ſhould alſo be well enlightened, otherwiſe

wiſe the pictures will be dull, obſcure, and no ways agreeable. You muſt therefore never exhibit but in a clear day, and it will anſwer beſt when the ſun ſhines upon the objects; that is, if the proſpect be weſtern, the appearance will be beſt in the morning; if eaſtern, in the afternoon; if northern, about noon. A ſouthern aſpect is the worſt of any for the camera obſcura.

A proper aperture ſhould be given to the lens; if the aperture be too ſmall, the picture will be dark and obſcure, and upon that account indiſtinct and unpleaſant. If the aperture be too large, the picture will be indiſtinct, on account of the aberration of the extreme rays, of which we ſhall ſpeak hereafter; and alſo becauſe the picture will be too much enlightened by the adventitious light which enters the room, by which it is much obſcured and injured.

The apertures will admit of ſome latitude, and may be more or leſs contracted, as the objects are more or leſs illuminated, or as they are nearer or farther from the lens. Mr. Harris ſays, that in a clear day, and the ſun ſhining obliquely upon the objects, a lens of 18 inches focus does beſt with an aperture from 1 to 1½ inch, according as the weather varies; when the weather was overcaſt, an aperture of 1¼ inch acted beſt; when the ſun ſhone, a lens of 30 inches focus bore an aperture of 1⅓, and would not bear more than 1¾ inch.

After every attempt to improve the picture, the apparent brightneſs will decreaſe nearly as the ſquare of the focal length of the lens is increaſed. For this apparent brightneſs will be nearly as the denſity of the light in the picture, divided by the denſity of the adventitious light in the room. And whatever is the focal length of the lens, the denſity of the adventitious light will be nearly as the ſquare of the linear aperture of the lens; and to preſerve the ſame denſity, the aperture muſt be as the focal length of the lens.

In ſome caſes the breadth of the picture may be about $\frac{2}{3}$ of it's diſtance from the lens, and even more if the paper be made a little concave; that is, the picture may take in a field of near 40 degrees; but in moſt caſes, when the field is ſo large, the picture will be more diſtinct in the middle than towards the extremes, and therefore you ſhould ſeldom exceed an angle of about 20 or 30 degrees.

A glaſs having both it's ſides ground flat, nearly parallel, and poliſhed on one ſide, will exhibit the images of objects vaſtly more vivid and diſtinct, than by reflection from paper, &c. The rays are not ſo much diſſipated in this caſe, as they are by reflection from the opake ſurface; you are alſo leſs offended by extraneous light, as none is admitted but what falls upon the glaſs, and paſſes through it, and you may therefore have a good picture by a much deeper or ſhallower lens than you have on the paper.

The inverted poſition of the images in a camera obſcura[*] is an imperfection; an inverted picture does not look near ſo pleaſant as one that is erect, and a perſon cannot be known near ſo readily in an inverted picture, as after the ſame picture is ſet in it's proper poſition. But if you take a looking-glaſs, and hold it before you with the face towards the picture, and inclining downwards, the images will be erect in the glaſs, and appear with greater luſtre than in the ſcreen; or you may place a ſmall mirror before or behind the lens, to inflect the rays before they come to the picture.

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[*] In portable inſtruments this inverſion is removed.

OF THE MAGIC LANTHORN.

The magic lanthorn has been generally applied to magnify ſmall pictures in a dark room for the amuſement of children: we ſhall ſhew you that it may be applied to more important purpoſes, by uſing it to explain the general principles of optics, aſtronomy, botany, &c.

The conſtruction and theory of this inſtrument is very eaſy; it conſiſts of a tin lanthorn with a tube fixed to the front; this tube conſiſts of two joints, one of which ſlides into the other; by drawing the outermoſt ſoint out, or puſhing it in, the tube may be made ſhorter or longer. At the end of this moveable tube a convex lens is fitted; the picture which is painted with tranſparent colours on glaſs, is placed in a groove made in the immoveable part of the tube, ſo that as the tube is lengthened or ſhortened, the lens will be either at a greater or leſs diſtance from the picture. In the inmoſt of the tubes, and as cloſe to the ſide of the lanthorn as poſſible, is placed a thick convex lens, in order to caſt a ſtrong light from the lamp upon the object.

To be more particular; in the inſide of the lanthorn, *fig.* 2, *pl.* 3, is a lamp L, whoſe light paſſes through the plano-convex lens N K L, and ſtrongly illuminates the object Q R, which is a tranſparent painting on glaſs, inverted, and moveable before the lens K L, by means of a ſliding frame in which the glaſs is fixed. The illumination is often increaſed by means of a concave mirror placed at the back of the lanthorn. If, when the object is properly illuminated, the lens S T be moved a little further from the object Q R than it's focal diſtance, it will form a repreſentation at a great diſtance on the oppoſite wall; and the image V W will be as much larger than the object Q R, as the diſtance Z O is greater than Z G. As the lens S T is moved farther out of, or puſhed into the tube, the image V W will be ſmaller or larger, according to the diſtance of the oppoſite wall.

To render the picture diſtinct, no light ſhould fall upon it but what paſſes through the lens, and for this reaſon the lanthorn muſt be uſed in a dark room. The lens ſhould be very convex, ſo that the object may be very near it; for you have ſeen, that by ſo much as the object is nearer to the lens, will the image be at a greater diſtance from it, and conſequently ſo much the larger; and ſince the image is inverted in order to make the picture on the ſcreen upright, it is neceſſary that the object ſhould be placed with the wrong end upwards.

FURTHER REMARKS ON THE PROPERTIES OF CONVEX LENSES.

Convex lenſes are uſed for looking at objects: to comprehend this, we muſt conſider their nature a little further. I have already told you, that when an object is very diſtant, the image is repreſented at the focus of the glaſs; and that the image is removed further from the lens, in proportion as the object approaches it; ſo that if the object is at the focal diſtance from the lens, the image is removed to an infinite diſtance. And for this reaſon, the rays Q N, O N, *fig.* 8, *pl.* 2, which fall upon the point O, are refracted by the glaſs, ſo that they become parallel to each other, as N F, and N F; and as parallel lines may be conſidered as proceeding to an indefinite diſtance; and that the image is always where the rays, which proceed from the object, are united after refraction; in the caſe where the diſtance OA of the object is equal to the focus of the glaſs, the image is removed to an infinite diſtance. As it is indifferent whether the parallel lines N F, N F, meet on the right or left hand, the image may be conſidered as being on either ſide, but at an infinite diſtance. From hence you will eaſily conclude, where the image will be found, when the object comes ſtill nearer the lens than the focus.

Let O P, *fig.* 10, *pl.* 2, be the object: now as the diſtance O A thereof from the lens is leſs than the focal diſtance, the rays O m, O m, which proceed from the object, are too diverging to be rendered parallel by refraction; but continue divergent, as N F, N F, after they have paſſed through the glaſs, but much leſs ſo than before; ſo that by prolonging them on the other ſide the lens, they will meet ſomewhere, as at *o*; conſequently N F, N F, after refraction follow the ſame direction as if they proceeded from the point *o*, and an eye which receives theſe rays will be affected as if they came from *o*, and will imagine that the object of viſion is at *o*: there will, however, be no image formed at *o*, and in vain would you apply a ſcreen there to receive it.

But an eye at E receives the ſame impreſſion as if the object O P exiſted at *o*. It is therefore important in ſuch caſes to know the ſize and place of the *imaginary* image o p. With reſpect to the place, it will be ſufficient to remark, that if the diſtance from the object A O was equal to the focal diſtance of the glaſs, the image would be at an infinite diſtance; but that as the object is brought to the lens, the more the imaginary image alſo approaches the glaſs, yet it's diſtance always exceeds that of the object from the glaſs.

To illuſtrate this by an example; let the focal diſtance of the glaſs be 6 inches, and the following tables will give you the diſtances of the object, as well as the correſponding diſtance of the imaginary image o p.

Diſtance

Diſtance of the object A O.	*Diſtance of the imaginary image* A c.
6	Infinite.
5	30
4	12
3	6
2	3
1	1 ⅕

The rule for finding the ſize of the imaginary image o p, is eaſy and general. - Draw a line C P p, through the extremity of the object, and c the center of the glaſs, and at p, where it meets the line o p, perpendicular to the axis of the glaſs, you find o p for the ſize of the imaginary image: from whence you ſee, that this image is always larger than the object; and that in proportion as it's diſtance from the glaſs exceeds that of the object from the glaſs: you alſo ſee, that the image is not inverted.

From theſe obſervations you will comprehend the uſe of convex lenſes to perſons who do not ſee near objects diſtinctly, but ſee well thoſe that are at a diſtance; for by the help of theſe glaſſes they ſee near objects as if they were at a diſtance.

OF CONCAVE GLASSES.

As convex glaſſes cauſe the rays of light to *converge* and *unite*, ſo thoſe which are concave make them *ſeparate* and *diverge*; for which reaſon, if diverging rays fall upon a concave lens, they will diverge more after they have paſſed through it than they did before; and ſuch rays as converge before their incidence, will, after their paſſage, converge leſs, their effect being directly contrary to that of convex lenſes.

Let us conſider their nature by a diagram, *fig.* 12, *pl.* 2, and O P as an object at a great diſtance, ſo that the rays O M, O M, may be deemed parallel. Theſe falling upon the concave glaſs are thereby rendered more divergent, and go on in the directions N F, N F, as if they had proceeded from the point *o*, although they really proceed from o.

As the rays are deemed parallel, if the glaſs had been convex, *o* would have been the focus; but ſince there is no real concurrence of the rays, this point is termed the imaginary focus of the concave lens, and ſometimes the point of *diſperſion*, as the refracted rays ſeem to diverge from this point.

Concave glaſſes have, therefore, no real focal point; but one that is imaginary, whoſe diſtance A o, however, is termed the focal diſtance.

When the object O P is at an infinite diſtance, the imaginary image *o p* is repreſented at the focal diſtance of the concave lens, and on the ſame ſide as the object; but though this image is imaginary, the eye is affected in the ſame manner as if the rays proceeded from that point.

When the object is nearer the glaſs, the image *o p* alſo approaches it; but ſo that the image is always nearer the glaſs than the object; whereas in convex glaſſes it is further from the lens than the object. To make this clearer, let us ſuppoſe, that the focal diſtance of the concave lens be 6 inches; the

Diſtance of the object O A.	*Diſtance of the image* O A.
Infinite	6
30	5
12	4
6	3
3	2
2	1 ½

The ſame rule as I gave you before determines the ſize of the image, by drawing a line from the center of the glaſs to the extremity of the object, which will paſs by p, the extremity of the image; this image is not inverted. Indeed, it is a general rule, that the image is always upright when it is on the ſame ſide of the glaſs as the object. The figure ſhews you, evidently, that in concave glaſſes the image is always leſs than the object.

You may now ſee why concave glaſſes are of ſuch uſe to ſhort-ſighted perſons, or thoſe who only ſee near objects diſtinctly; for they will repreſent diſtant objects to them in the ſame manner as if they were really very near.

A *meniſcus* has the properties of a convex lens, when the inner radius is the greater, and of a concave when the inner radius is the ſmalleſt. If the two ſurfaces are concentric, it has the properties of neither; for the rays will then emerge parallel. If the radius of convexity be leſs than the radius of concavity, then the *meniſcus* will have all the properties of a convex lens of the ſame focal diſtance. If the radius of the concavity be leſs than the radius of convexity, then the meniſcus will have all the properties of a concave lens, whoſe focal diſtance is the ſame.

When any ſmall object, or any point of that object, is ſeen by refracted light, it appears in the direction of that line, which the rays deſcribe after their laſt refraction.

If the rays, that come from any ſmall object, paſs through a glaſs priſm, of which A C B, *fig.* 6, *pl.* 3, is a ſection, the ray D E will be refracted towards a perpendicular, when it enters the priſm, and will deſcribe the line E F, and when it goes out of the glaſs it will be refracted from a perpendicular into the line F G; which line is the direction of it after it's laſt refraction, and the object

D will be ſeen at L, inſtead of D; for in this and all other caſes of the ſame ſort, the picture of the object on the retina will be in the ſame place that it would have been if the eye had been really looking at an object placed at L; for the refraction gives the rays the ſame direction as if they had come originally from L.

From hence we underſtand why an object ſeen through *a multiplying glaſs*, or through a glaſs that is cut into different ſurfaces inclined to one another, appears, at one view, in many different places. If the object F is ſeen through the glaſs a b c d, *fig.* 7, *pl.* 3, by the ray A B, that paſſes through the ſurface c b, the object by the eye at A, will be ſeen at B, the ray D d paſſes through the ſurface c d, and when it is refracted comes to the eye in the direction A D, as if it proceeded from D, and therefore the object appears at D; and for the ſame reaſon through the ſurface a b, it appears at C; conſequently there will be the appearance of as many objects as there are ſuch ſurfaces on the glaſs, for each of them ſhews the ſame object in a different place. If ſuch a glaſs be ſhaken before the eye, the objects on the other ſide will appear alſo to ſhake, as the ſituation of the ray by which it is ſeen will be varied with every motion of the glaſs.

In refracted viſion, it is not the object itſelf we ſee, but the laſt image of it, which conſiſts of all the imaginary radiants, or points, from whence the rays appear to diverge after their laſt refraction. That you may the better underſtand what I here mean by the laſt image, let *fig.* 12, *pl.* 3, be an object nearer to a convex lens than it's principal focus. The rays that diverge from any point b in this object will, by paſſing through the lens, be made to diverge leſs, and the imaginary radiant will be more remote than the real one. Thus the rays b g, b l, when they have gone through the lens, will not proceed ſtrait forward in the lines g k, l p; but will be refracted into the leſs diverging directions g m, l n, as if they had come from the imaginary radiant e, which is more remote than the real one b. The ſame will happen to the rays that come from a, or c, or any other point in the object; ſo that there will be ſomewhere behind the lens, as at d f, as many imaginary radiants as there are real ones in the object, and theſe imaginary radiants taken all together compoſe the laſt image. And ſince all the rays fall upon the eye, as if they had diverged from this laſt image, the eye will be affected by the object a b c, juſt in the ſame manner when it looks through the lens, as it would be without the lens, by an object in all reſpects like d e f, or as it would by the laſt image, if without the lens the laſt image could be made viſible; and becauſe the eye is affected when it looks through the lens, as if d e f was the object, and not a b c, therefore we ſay, that it is not the object itſelf, but it's laſt image that we ſee.

This is univerſal; in refracted viſion the eye is affected by the rays of light after refraction, as if they had come not from the object itſelf, but from it's laſt image, which conſiſts of all the imaginary radiants from whence the refracted rays appear to diverge at the time they fall upon the eye.

TO FIND THE FOCAL LENGTHS OF LENSES BY EXPERIMENTS.

1. When the focal length of the lens does not exceed two or three feet, it may be found by holding the lens at ſuch a diſtance from the wainſcot oppoſite a window ſaſh, that the image of the ſaſh may be diſtinct upon the wainſcot, and this diſtance may be conſidered as the focal length of the lens;

but if the focal length is long, you muſt compute the focus by the ſubſequent rule.

RULE.

Meaſure the diſtance between the lens and the object, and alſo from the image; multiply theſe diſtances together, and divide the product by their ſum; the quotient will give the focal diſtance. Or, the ſquare of the diſtance of the obſerved focus, divided by the diſtance of the object from the image, will give the exceſs of the obſerved focus beyond the true focal diſtance.

2. You may find the focus by making a candle the object. To do this, move the lens or the candle, and the paper for receiving it's image, ſo that when the image is moſt diſtinct the lens may be exactly between the other two; then halve the diſtance between the object or it's image, and the lens is the focal diſtance.

3. If a ſmall hole about ¼ or ⅛ of an inch be made in the window ſhutter of a darkened room, and a lens and piece of paper be held behind this hole at proper diſtances, the place where the image of the hole is diſtincteſt, may be determined very critically, and from thence the focal length may be found by the foregoing rule.

4. By the ſun's image. Place the lens ſo that it's axis may point as near as poſſible to the ſun; then holding a paper oppoſite thereto, the burning point, or where the image of the ſun is ſmalleſt, and the limb moſt diſtinct, is the focus. This method is ſufficiently accurate for ſpectacle glaſſes and reading glaſſes, and ſuch as are broad in proportion to their focal length; but will not anſwer for lenſes of a long focus, unleſs they are ſufficiently long to exhibit the ſolar ſpots; becauſe in theſe caſes the image is only a glare of light without

diſtinctneſs; but the inconveniences may be removed by the following method.

5. Cover the lens with a piece of paſteboard or paper, and make two round holes therein at an equal diſtance from the edge of the lens, and on one of it's diameters. The lens being thus covered, point it's axis to the ſun: now if a paper be held behind the lens, you will find the two circles or white ſpots produced by the two holes, gradually approach nearer to each other as the paper is moved further; at laſt they will coincide; and if the paper be moved ſtill further, they will again ſeparate. The diſtance of the paper from the glaſs when the circles unite being meaſured, gives the focal diſtance.

TO FIND THE FOCAL LENGTH OF A CONCAVE LENS.

Let the lens be covered with paper, having two ſmall circular holes; and on the paper for receiving the light deſcribe alſo two ſmall circles, but with their centers at twice the diſtance from each other of the centers of the circles. Then move the paper to and fro till the middle of the ſun's light, coming through the holes, falls exactly on the middle of the circles; that diſtance of the paper from the lens will be the focal length required.

TO FIND THE FOCUS OF A PLANO-CONVEX AND A PLANO-CONCAVE LENS.

By ſimilar experiments you will find, 1. That the focus of a plano-convex, or of a plano-concave glaſs, is equal to a diameter of it's convex or concave ſurface, that is, of the whole ſphere it belongs to.

2. That the focal diſtance of a double convex or double concave glaſs, of equal convexities or concavities, is equal to a ſemi-diameter of either of it's ſurfaces; and conſequently that the focal diſtance of a glaſs of unequal convexities or concavities, will have an intermediate length between a diameter and ſemi-diameter, of that ſurface which is moſt convex or concave.

TO MEASURE THE FOCAL DISTANCE OF A GLOBE OF WATER AND OF GLASS.

Take a hollow globe of glaſs, or inſtead of it a thin round flaſk or decanter, and making a moderate round hole about an inch diameter, in a piece of brown paper, paſte it on one ſide of the belly of the decanter; and having filled it with water, hold the covered ſide to the ſun, that the perpendicular rays may paſs through the middle of the water, and the emergent rays will be collected to a focus, whoſe neareſt diſtance from the decanter will be equal to the ſemidiameter of the belly of it; as will appear by receiving the rays upon a paper, held at that diſtance. That this effect is owing to the water, and not to the glaſs, will be evident by emptying the decanter; for the light that paſſes then through the hole, will then be as broad as the hole itſelf, at all diſtances of the paper from the decanter. If a ſimilar experiment be tried, with a ſolid globe or ball of glaſs, the diſtance of the focus from the neareſt part of the ball will be one quarter of it's diameter.

TO FIND THE VERTEX OR CENTER OF A LENS.

Hold the lens at a proper diſtance from the eye, and obſerve the two *reflected* images of a candle made by the two ſurfaces. Move the lens till theſe images coincide, and that point is the vertex; and if this be in the middle of it's ſurface, the glaſs is truly centered, otherwiſe it is not.

The theory of real images is eaſily illuſtrated by experiment. For this purpoſe I ſhall draw a long line on the table, and place this convex lens at A, *fig.* 7, *pl.* 2, whoſe principal focus are at F and f. Now ſet off theſe diſtances on each ſide of A, and then ſet off the diſtance A F on the part of the line A B, marking the parts ſo ſet off, 1, 2, 3, 4, &c. On f D make f 1 equal to A f, and divide it into f$\frac{1}{2}$, f^{3}, f$\frac{1}{4}$, &c. ſo that theſe parts be reſpectively equal $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. of f 1 or A f. This done, let us darken the room, and place a lighted candle over the diviſion marked 2; the image of the candle will then be ſeen diſtinct but inverted, upon a paper held over the correſponding fraction on the other ſide at $\frac{1}{2}$. If you place the candle at 3 or 4, the paper for receiving the images muſt be held over $\frac{1}{3}$ or $\frac{1}{4}$, &c. So that if the candle be moved from 2 to an infinite diſtance, the whole motion of the image will be from $\frac{1}{2}$ to f; if the candle be at 1, the image will be at 1 on the other ſide. If the candle be brought nearer to F, the motions of the image and candle will be reciprocal to what they were before. But if the candle be placed any where between F and the lens, there will be no image formed.

OF THE DEGREES OF BRIGHTNESS AND DISTINCTNESS OF AN IMAGE.

Whatever be the ſhape and magnitude of the hole in the paper that covers part of a lens, the ſhape and magnitude of the image will be the ſame as when the lens is *uncovered*; becauſe any ſmall part of a pencil of rays has the ſame focus as the whole: but the brightneſs of the picture will be diminiſhed, in proportion as the hole in the cover is diminiſhed; becauſe the quantity of light which illuminates every point of a picture is diminiſhed in that proportion.

A GENERAL VIEW OF THE PROPERTIES AND PHENOMENA OF SINGLE LENSES, DEDUCED FROM THE PRINCIPLES ALREADY ADVANCED. *

Let RF, *fig.* 1, *pl.* 4, be conjugate foci; P, p, the principal foci. By *conjugate foci* are meant two points ſo ſituated, that either of them being the *radiant*, the other will be the *focus*.

Then, 1. Parallel rays falling on one ſide of a convex lens, A, will be refracted to P, or p, on the other ſide, *fig.* 1, *pl.* 4.

2. Parallel rays falling on one ſide of a concave lens, A, *fig.* 2, *pl.* 4, will by refraction diverge from P, or p, on the ſame ſide.

3. In a convex lens, rays diverging from P or p, *fig.* 1, *pl.* 4, will emerge parallel on the other ſide.

4. In a concave lens, *fig.* 2, *pl.* 4, rays converging to p or P, will emerge parallel, going out on the ſame ſide.

5. In convex lenſes, rays, *fig.* 1, *pl.* 4, diverging from R beyond P will converge to F beyond P, and the contrary.

6. In convex lenſes, rays diverging from R, *fig.* 3, *pl.* 4, which is nearer P, will diverge from F on the ſame ſide with R.

7. In convex lenſes, rays converging to F, *fig.* 4, *pl.* 4, will by refraction converge to R, nearer than P or f.

8. In concave lenſes, rays converging to R, *fig.* 2, *pl.* 4, beyond P, will diverge from F beyond p, and the contrary.

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* Emerſon's Elements of Optics, p. 125.

9. In concave lenſes, rays converging to F, *fig.* 5 and 6, *pl.* 4, nearer than p, will by refraction converge to R beyond F.

10. In concave lenſes, rays diverging from R, *fig.* 7, *pl.* 4, nearer than p, will diverge from F nearer than p.

11. In concave lenſes, rays diverging from R, *fig.* 8, *pl.* 4, nearer than p, will diverge from F nearer ſtill than p.

A meniſcus may be conſidered as convex or concave, according as the center of it's inner ſurface is further off or nearer than the center of the outward ſurface.

The length of an object is to the length of the image made by a lens, as the diſtance of the object from the center of the lens, to the diſtance of the image from the lens.

The area of the object is to the area of the image, as the ſquare of the object's diſtance from the lens is to the ſquare of the image's diſtance therefrom.

A convex lens magnifies an object, when it is nearer than twice the principal focal diſtance; but if further off, the object is diminiſhed.

A concave lens diminiſhes an object in all caſes.

If the object and it's image be both on the ſame ſide of the lens, the image will be *erect*; if they be on different ſides, the image will be *inverted*.

When the object and image are on different ſides of the lens, as the object approaches the lens, the image recedes from it; or if the object recedes, the image approaches.

If the object and image be both on one ſide of the lens, if the object moves towards the lens, the image alſo moves towards it; and the contrary.

In a convex lens, if the object be beyond the principal focus, it's image will be on the other ſide of the glaſs, and inverted. But if the object be nearer than the principal focus, the image will be on the ſame ſide of the glaſs, and erect.

The diſtance and magnitude of the image may be increaſed at pleaſure, by cauſing the object to approach the principal focus.

In a concave lens, the object and image are always on one ſide of the lens.

The image made by a lens, becomes viſible by placing the eye to receive the diverging rays going from the image, at a proper diſtance for diſtinct viſion.

The image formed in the air by a lens, may not only be ſeen by the eye placed in the diverging rays, but it may alſo be ſeen upon a piece of paper placed at the focus.

If an object be placed at the principal focus of a lens, it's apparent magnitude at any place beyond the lens will be invariably the ſame, and equal to the apparent magnitude when ſeen from the center of the lens with the naked eye; ſo that the apparent magnitude of an object placed in the principal focus, will continue, whether the eye be moved nearer to or further from the lens.

The nearer the eye is to a lens, the more of the object appears; the farther off, leſs of it is perceived.

If the object be nearer than the principal focus, it's apparent magnitude grows leſs in going from the glaſs. If the object be further, the apparent magnitude is increaſed, when the eye goes further from the glaſs.,

If the eye be fixed at the principal focus, the apparent magnitude of an object will be invariably the ſame, wherever the object is placed beyond the glaſs.

If the eye be fixed at a leſs diſtance than the principal focus, the apparent magnitude of an object is diminiſhed, though by ſlow degrees, as it is removed from the lens.

If the eye be fixed at a greater diſtance than the principal focus, the apparent magnitude of an object is increaſed, as it is removed from the glaſs, till it comes to the conjugate focus in reſpect to the eye, and then it becomes infinite and confuſed, and begins to be inverted, and going further off is again diminiſhed.

If the *eye and the object* be fixed, and a concave lens be moved from either of them to the other, the apparent magnitude of the object will decreaſe to the middle, and then increaſe again.

The brightneſs of an image formed by a lens from a luminous object, will be as the area of the lens directly, and the ſquare of the diſtance reciprocally.

Though the brightneſs of the image increaſes with the area of the glaſs, the diſtinctneſs decreaſes; for it is only the rays very near the vertex that are refracted to a ſingle point in the picture; thoſe that are farther off deviate more and more, and thus render the picture confuſed.

Other phenomena of lenſes will be conſidered in the courſe of theſe Lectures, which cannot be ſo well treated of till I have explained the nature of viſion. You now begin to be acquainted with the properties of another ſubtil agent, whoſe particles are immenſely minute, whoſe progreſs is aſtoniſhingly rapid, whoſe power and influence is beyond comprehenſion, maintaining an intercourſe between ſyſtems, and diffuſing numberleſs bleſſings in it's progreſs.

You have ſeen that a body, fit to reflect light and exhibit colours, when placed in the light, not only returns the rays of light that fall upon it, to the luminous body by which it was enlightened, but ſends the picture of itſelf quite round the hemiſphere in all directions, and to every point. Place a thouſand, a million of ſuch bodies near each other, each performs the ſame operation; the rays of light and their colours come inſtantaneous to the ſpectator's eye from each, without being diſturbed or diverted in their paſſage by the numberleſs rays returned in different directions by other contiguous bodies. You have ſeen the vehemence with which this agent, whoſe parts are ſo wonderfully minute, acts when it's rays are collected by the burning-glaſs; that no terreſtrial ſubſtance was capable of withſtanding it's effects without being deſtroyed, or decompoſed. Some of the effects produced by glaſſes of different figures, have been explained to you. You have alſo ſeen objects ſeemingly ſuſpended in the air, where nothing was to be found that was ſenſible to the touch. In the camera obſcura, you ſaw nature draw her own picture inverted, and in miniature: you ſaw a picture painted in a moment with a beauty, a vivacity, and ſoftneſs of colours, that would make a landſcape drawn by the firſt artiſts appear faint and languid: the picture of the camera was animated, the trees were agitated by the winds, the flocks bounded upon the lawn, and the ſun-beams played upon the water: and you learnt that all theſe ſcenes depended upon the *refraction* of the rays of light, and were made acquainted with the laws of this refraction. In the xviith Lecture you will ſee theſe laws applied to explain the nature of viſion.

I cannot finiſh this Lecture without pointing out to you the analogy between the light of revelation, and the light of the heavens:* the ſimilitude is ſuch, that the language belonging to one may with great propriety be transferred to the other. As the *firſt knowledge* of *religion* was revealed by GOD; ſo the *firſt material light* was created by him. GOD, who alone is the living light of ſpirit, ſoul, and ſentiment; the perpetual fountain of every ſtream of beauty and truth; HE ſaid, LET THERE BE LIGHT; and inſtantly the internity of his ever-living light kindled up an externity of corporeal irradiation, that has it's effluence from him, and cannot beam but by him.

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* Barton's Analogy of Divine Wiſdom.

Though the ſolar light is perpetually ſhining forth, it falls very unequally on the world: in ſome places the day is equal to months, in others it's duration is only that of a few hours. It comes pure from it's ſource, but often meets with a foul atmoſphere in it's courſe that obſcures it, and changes it's direction. It ſhews many things different from what they are, but never miſleads any one. It ſhines indifferently on all objects, is totally rejected by ſome, tranſmitted by others, bent and diſtorted by a third kind, and uſefully imbibed by a fourth. It is the means of the knowledge of many things, yet it's own nature is but little known. It enlightens and enlivens the world, and promotes the vegetation of poiſon as well as of wholeſome food.

Is not all this equally true of the light of revelation, as of material light? They that cenſure the one, may find pretences equally ſtrong to traduce the other; and whatever objections the infidel points againſt the ſcriptures, will be found to apply equally ſtrong againſt the manifeſtation of God in the viſible courſe of nature.

LECTURE XVI.

OF CATOPTRICS.

AFTER having explained to you, as conciſely as I am able, the laws of refraction, and the effect produced by theſe laws; I ſhall proceed to explain the doctrine of *catoptrics*, or that part of *optics* which treats of the *reflection of light*. You will here, among other things, learn how the figure of a man ſix feet high is ſeen in a glaſs mirror not above three feet; how in a convex mirror figures are reduced to a Lilliputian ſize, and in a concave mirror expanded to a gigantic ſize; wonders that the curious would wiſh to comprehend, and the inexperienced to examine.

Before *Newton* publiſhed his diſcoveries concerning the nature and properties of light, it was a principle generally received, that the rays of light were reflected, as other bodies, by ſtriking on their ſolid and impervious parts, as you ſee a marble bound when ſtruck upon the pavement. Newton taught mankind, that the particles of light are turned back before they touch the reflecting body, by ſome *power* which is equally diffuſed all over the ſurface of the body.

If, ſays he, the rays of light were reflected by impinging on the ſolid parts of bodies, their reflections from ſolid bodies could not be ſo regular as they are; for however poliſhed the ſmootheſt object may ſeem to our ſight and touch, yet it is in fact one continued aſſemblage of inequalities. For in poliſhing glaſs with ſand, putty, or tripoly, it is not to be imagined, that thoſe ſubſtances can by grating and fretting the glaſs bring all it's leaſt particles to an accurate poliſh, ſo that all their ſurfaces

faces ſhall be truly plane, or truly ſpherical, and look all the ſame way, or compoſe one even ſurface. The ſmaller the particles are, the ſmaller will be the ſcratches by which they continually wear away the glaſs until it be poliſhed; but be they ever ſo ſmall, they can wear away the glaſs no otherwiſe than by grating and ſcratching, and breaking the protuberances, and therefore poliſh it no otherwiſe than by bringing it's roughneſs to a very fine grain, ſo that the ſcratches and frettings of the ſurface become too ſmall to be viſible. From ſuch a ſurface it cannot be ſuppoſed, that rays will be reflected with ſuch uniformity as we uſually obſerve: on the contrary it is highly probable, that if light were reflected by impinging on the ſolid parts of glaſs, it would be ſcattered as much by the moſt poliſhed, as by the rougheſt ſurface.

It is therefore a *problem*, how glaſs poliſhed by fretting ſubſtances, can reflect light in ſo regular a manner; and this *problem* is ſcarce otherwiſe to be ſolved, than by ſaying that the reflection of a ray is not effected by the reflecting body, but by ſome power of the body which is regularly diffuſed all over it's ſurface, and by which it acts upon the ray without immediate contact, ſo that it is reflected before it arrives at the ſurface.

A ray of light can fall but two ways upon a mirror, that is, either perpendicularly or obliquely; and experience has proved, that when light is reflected, the *angle of reflection is always equal to the angle of incidence*. Thus, ſuppoſe a b, *fig.* 25, *pl.* 1, to be the ſurface of a plane mirror, if a ray of light f c falls perpendicularly thereon, it is reflected in the ſame direction, making ſtill a right angle with the mirror. If it falls in an oblique direction, &c. it is reflected in the direction c d, making with the mirror the angle of reflection d c b perfectly equal to the angle of incidence e c a.

I ſhall prove this to you by two experiments; firſt, I ſhall let a ray paſs through a hole into a dark chamber, and fall obliquely upon a plane mirror; you will find, that at equal diſtances from the point of reflection, the incident and reflected ray will be the ſame height from the ſurface.

It is more accurately proved by the braſs circle uſed before, *fig.* 5, *pl.* 2. I place the two radii at equal angles from the diameter: now if you look through the hole or ſight down upon the center of the mirror, you will ſee the point of the other radii; which proves, that the ray which comes from that point is reflected from the center of the mirror to the eye, in the ſame angle in which it fell on the mirror.

This axiom, that the *angle of reflection is always equal to the angle of incidence,* holds good in every caſe of reflection, whether from plane or ſpherical ſurfaces, and that whether they are convex or concave.

All reflection is reciprocal. If the ray e c, after it has been reflected in the line d c, is turned back again in that direction, it will be reflected into e c; therefore if d c b is the angle of incidence, e a c will be the angle of reflection; and if *e c a* be the angle of incidence, d c b will be the angle of reflection.

This general law, that *the angle of incidence is always equal to the angle of reflection,* is the foundation of all catoptrics, and is ſufficient for demonſtrating all the phenomena thereof: other laws are only conſequences deducible from this principle, or applications thereof to particular effects.

With reflected as with refracted rays, it is neceſſary that ſeveral rays ſhould act at the ſame time, in order to make an impreſſion on our eyes; theſe rays may be diſpoſed differently with reſpect to each other; they may be either parallel, convergent, or divergent; and the ſurface on which they fall, may be either plane, convex, or concave. Each of theſe circumſtances we ſhall conſider ſeparately.

1. *Parallel rays falling upon a plane mirror are parallel after reflection.*

The parallel rays d b, c a, *fig.* 1, *pl.* 5, are reflected from the ſurface a b to h and k, making the angle of reflection i b h equal to the angle of incidence f b d, and the angle of reflection g a k equal to that of incidence e a c; and conſequently from the principle of geometry the two rays d b, e a, are parallel after reflection.

This may be proved alſo by letting two parallel rays (in a dark chamber) fall upon a mirror; and you will find that they retain their paralleliſm after reflection in every inclination of the mirror.

2. *When incident diverging rays are reflected from a plane mirror.*

The diverging rays d b, c a, *fig.* 2, *pl.* 5, are reflected to h and k, and have the ſame degree of divergence at F as they would have had at E. If they had gone on in their firſt direction, the points at F and F are equally diſtant from the points of contact a and b; therefore *the divergence of the rays is the ſame after reflection as before.*

3. *When incident converging rays falling upon a plane mirror are reflected therefrom.*

The converging rays d b, c a, *fig.* 3, *pl.* 5, if the mirror were not interpoſed, would meet at E, but are ſo reflected from a and b, as to make the angles of reflection g b k, e a h, equal to their reſpective angles of incidence f b d, e a c, and unite in F, a point at the ſame diſtance from a and b as the point E: *their convergence after reflection is therefore the ſame as before it.*

Let us now conſider a *convex* ſurface, and you will find,

1. *That parallel rays falling upon a convex ſurface are rendered diverging by reflection.*

2. *That converging rays, when reflected from a convex ſurface, become leſs convergent,* and may be rendered parallel, or even diverging, according to the degree of convexity of the reflecting ſurface.

3. *Divergent rays are rendered more diverging,* ſo that a convex ſurface always tends to ſcatter the rays by diminiſhing their convergence, and increaſing their divergence.

As every curved ſurface may be conſidered as formed of an infinite number of ſmall ſtrait lines, which conſtitute the elements thereof; I ſhall, to render this ſubject more clear, repreſent a convex ſurface by two ſtrait lines inclined to each other: by thus making the elements conſpicuous, you will more readily comprehend why the rays of light, when reflected from a convex ſurface, take a different direction from what they had when they fell upon the mirror.

Let b d, *fig.* 4, *pl.* 5, repreſent a convex mirror, and a b, c d, *parallel* rays falling thereon; and becauſe the angles of reflection c b f, h d i, are always equal, the rays are, as you ſee by the figure, rendered diverging, and proceed to e and h.

In the ſame manner the *converging* rays a b, c d, *fig.* 5, *pl.* 5, which if the mirror b d were not interpoſed would unite in m, have their direction ſo changed by reflection, that they proceed to and unite at l, much further from the points of contact b and d, than the point *m;* and you muſt perceive from the figure, that the inclination of the two elements b d, may be ſo increaſed as to render them parallel, or even diverging.

Thus the rays a b, c d, *fig.* 6, *pl.* 5, which without the interpoſition of the mirror would diverge but very little at m, are thereby rendered more diverging; ſo that they are much further apart at l, than at m.

We have now only to conſider the direction of rays of light when reflected from a concave ſurface; and here you will find,

1. *That parallel rays are by reflection made converging.*

2. *That converging rays become more convergent.*

3. *That diverging rays become leſs divergent.*

A view of the diagrams is ſufficient to prove the truth of theſe propoſitions.

Let b d, *fig.* 7, *pl.* 5, repreſent a concave mirror; the rays a b, c d, which were parallel before reflection, are by the laws thereof made to converge in l.

The rays a b, c d, *fig.* 8, *pl.* 7, which, without the interpoſition of the mirror, would unite at m, are thereby ſo reflected as to meet at l, nearer the points of contact b d than m.

Laſtly, the rays a b and c d, *fig.* 9, *pl.* 5, which before reflection were divergent, converge after reflection meeting at o.

From the principles thus laid down, it is eaſy to ſee what will be the effect of mirrors, and to explain the principal phenomena which they occaſion. By a *mirror*, or *ſpeculum*, we, in general, mean any ſubſtance whoſe ſurface is ſufficiently poliſhed to reflect uniformly the greater part of the rays which fall upon it, and to exhibit an image of the objects placed before it. They are generally divided into *plain*, *convex*, and *concave* mirrors: there are beſides theſe *conical* and *cylindrical*, *pyramidical* and *priſmatical* mirrors.

OF PLANE MIRRORS.

It will be neceſſary here to remind you of what has been already mentioned; namely, that a pencil of rays emanating from any given point of ſpace, is the means by which the ſight aſſures us, that a body exiſts at or in that point; it is plain, therefore, that we are liable to deception in that reſpect; for if the pencil be ſo affected by reflection (or refraction) as to proceed with different divergency or direction, that is, in the ſame direction as it would have proceeded if coming from ſome other point, the ſenſe will refer the place of the object to the point, which is in the direction of the laſt courſe of the rays.

In a plane mirror a b, *fig.* 10, *pl.* 5, the image of an object c appears to an eye at e, behind the mirror in the direction e g, and always in the interſection g, of the perpendicular c g, and the reflected ray e g, and conſequently at g, as far behind the mirror as the object c is before it. We therefore ſee the image in the ſame place, whereſoever the reflected ray be by which it is perceived; for as a plane mirror does not alter the relative poſition of the rays which fall on it, the diverging rays proceeding from c, are reflected towards the eye e, by the mirror a b, with the ſame degree of divergence, and have their imaginary point of union g at the ſame diſtance behind the mirror that c is before it.

For the ſame reaſon a plane mirror does not change, or alter the figure or ſize of objects; but the whole image is equal and ſimilar to the whole object, and has a like ſituation with reſpect to one ſide, of the plane that the object has with reſpect to the other; for the converging rays K m, L n, *fig.* 11, *pl.* 5, proceeding from the extremities of the object K L, and falling upon the mirror a b, are reflected towards the eye e with the ſame degree of convergence, and conſequently ſhew the image k l under an angle equal to that by which the object would be ſeen from the point i, if the mirror were not interpoſed.

From what has been explained, it follows, that if an object K L is inclined to a plane mirror, it's image k l will be inclined thereto in a contrary direction.

If an object A B, *fig.* 12, *pl.* 5, be placed parallel to a plane mirror C D, and at the ſame diſtance therefrom as the eye o; the part of the mirror C D, on which the rays A C, B D, from the object fall, which are reflected to the eye, will be *one half* the length of A B. For the image being as far behind the glaſs as the object is before it, the rays O G, O H, are each divided at the middle of the mirror C D, and conſequently where they only ſpread half as much, as they would do at double the diſtance. Therefore to ſee the whole of an object in a mirror, the length and breadth of the mirror muſt be half the length and breadth of the object. Hence if the length and breadth of an object be given, it is eaſy to determine the ſize of a mirror that will ſhew the whole of an object when placed at the ſame diſtance therefrom as the eye.

Hence a perſon viewing himſelf in a plane looking-glaſs, placed upright, will ſee his image complete in a part of the glaſs, whoſe length and breadth is equal to half the length and breadth of the correſponding parts of his own body; and this will be always the caſe at whatever diſtance he ſtands from the glaſs.

A ſpectator will ſee his own image as far beyond the ſpeculum as he is before it; and as he moves to or from the ſpeculum, the image will, at the ſame time, move towards or from him on the other ſide; but apparently with a double velocity, becauſe the two motions are equal and contrary. In like manner, if, while the ſpectator is at reſt, an object be in motion, it's image behind the ſpeculum will be ſeen to move at the ſame rate. And if the ſpectator moves, the images of objects that are at reſt will appear to approach, or recede from him, after the ſame manner as when he moves towards real objects; plane mirrors reflecting not only the object, but the diſtance alſo, and that exactly in it's natural dimenſions.

One principle is ſufficient for explaining, with facility, the phenomena of objects ſeen in a plane mirror. It is this: *That the image of an object, ſeen in a plane mirror, is always in a perpendicular to the mirror joining the object and the image; and that the image is as much on one ſide the mirror as the object is on the other.* With the aſſiſtance of this principle and a little geometry, you may readily ſolve the principal queſtions that can be propoſed on this ſubject.

The celebrated Archimedes, at the ſiege of Syracuſe, is ſaid to have deſtroyed the ſhips of Marcellus, by a machine compoſed of ſpeculums, Since a plane ſpeculum, in theory, reflects all the light, which is incident under the ſame affections with which it was incident, the rays of the ſun coming from a vaſtly diſtant object may be conſidered as parallel, and will be reflected parallel to each other, and conſequently will heat and illuminate any ſubſtance in the ſame manner as if the ſun ſhone upon it. Two ſpeculums, which reflect the light on the ſame ſubſtance, will heat it twice as much as the ſun's direct light. Three will heat it three times as much; and by increaſing the number of ſpeculums, a prodigious degree of heat may be produced.

Though a plane ſpeculum is ſuppoſed, in theory, to reflect all the light which falls upon it, yet in practice *almoſt half the light is loſt* on account of the inaccuracy of the poliſh, and the want of perfect opacity in the ſubſtance of the mirror. Notwithſtanding this, M. Buffon, in 1747, conſtructed a burning machine of this kind. It conſiſted of 168 plane mirrors, each 8 inches long, and 6 broad, ſo contrived that the focal diſtance might be varied, and alſo the number of glaſſes, as occaſion required. In the month of March, 1747, with 40 glaſſes he burnt a plank at the diſtance of about 70 feet.

OF CONVEX MIRRORS.

Convex mirrors ſpread or diverge reflected rays; they render parallel rays diverging; they diminiſh the convergence of converging rays; in ſome caſes they render them parallel, and even divergent.

Let us ſuppoſe an object d e, *fig.* 13, *pl.* 5, placed before a convex mirror a b. Of the two cones of rays proceeding from the extremities of the object, the rays d p, and e p, which if the mirror were not interpoſed would proceed to and unite at p, are reflected leſs converging on the line f g; the rays d k, e l, which would have converged at m, are reflected parallel; the two rays d h, and e i, which would have met at c the center of convexity, are reflected back on themſelves, becauſe of the perpendicularity of their incidence; they are, however, diverging; and all the rays proceeding from points beyond the two laſt will be reflected more diverging.

In *convex mirrors*, as well as thoſe that are plane, the image always appears erect, and behind the reflecting ſurface, but differs from it in other reſpects; for, 1. *The image, in a convex mirror, is always ſmaller than the object,* and the diminution is greater in proportion as the object is further from the mirror. This will appear clear to you on reflecting on the properties of a reflecting convex ſurface, that incident converging rays are thereby rendered leſs convergent: thus let C D, *fig.* 14, *pl.* 5, be an object placed before a convex mirror a b, two rays C e, D d, proceeding from the extremities of the object, theſe, if the mirror were not interpoſed, would converge at f; but are reflected by the mirror leſs converging, ſo as to meet at i, thus forming a more acute angle; the object appears ſmaller than it would have done if it had been viewed from the point f. 2. *The image does not appear ſo far behind the reflecting ſurface as in a plane mirror.* Let G, *fig.* 15, *pl.* 5, be a point of any object, from whence a diverging cone of rays proceeds, and falls upon the mirrors; theſe rays are reflected more diverging, and have conſequently their imaginary focus, or point of union, g, much nearer, by which means the image appears to be nearer the reflecting ſurface than the object; and this effect increaſes in proportion to the convexity of the mirror. Concave mirrors have a real focus, convex mirrors only a virtual focus, and this focus is behind the mirror, diſtant therefrom half the radius of it's convexity.

The image of a ſtrait object, not too ſmall, and placed parallel or oblique to the mirror, is ſeen curved in the mirror, becauſe the different points of the object are not all at an equal diſtance from the ſurface of the mirror. The point o, *fig.* 14, *pl.* 5. for example, of the object d e is nearer than the reſt to the ſurface of the mirror, the extreme points d e are more diſtant; they will of conſequence be repreſented behind the mirror, at diſtances proportional to thoſe at which they are placed before, whence it becomes bent or curved.

OF CONCAVE MIRRORS.

I have already ſhewn you, that it is the property of concave mirrors to collect the rays of light they reflect, converging parallel rays, increaſing the convergence of thoſe that are already converging, diminiſhing the divergence of diverging rays, in ſome caſes rendering them parallel, and even convergent. Theſe effects are all in proportion to the concavity of the mirror.

The point where the rays unite is called the *focus* of the mirror; but this focus is not the ſame for all kinds of incident rays. Parallel rays a b, d e, falling upon a concave mirror m o, are reflected ſo as to unite at F, *fig.* 16, *pl.* 5, which point is diſtant from it's ſurface ¼ of the diameter of the ſphere of the mirror; this point is called the focus of parallel rays, or *true focus of the mirror.* Converging rays, ſuch as f g, h i, are reflected more converging, and unite at K, between the focus of parallel rays and the mirror. Laſtly, diverging rays proceeding from a point further from the mirror than the true focal point, as R m, R o, are reflected converging, and meet at a point P, further from the mirror than the focal point of parallel rays. But if the point K, from which the diverging rays proceed, is nearer the mirror than the point E, they are diverging; that at g would proceed to f, and that at i towards h.

The *focus* therefore of parallel rays is at one fourth the diameter of the ſphericity of the mirror. The focus of converging rays is nearer the mirror than that of parallel rays; but the focus of diverging rays is more diſtant.

Plane and convex mirrors exhibit their images as if behind the mirror and erect. The effect of concave mirrors is different; they only ſhew the image behind the mirror and erect, when the object is placed between the mirror and the focus of parallel rays, and then the image is larger than the object. Let A B *fig.* 17, *pl.* 5, be an object placed before a concave mirror E F, but nearer than the focus of parallel rays: the two rays A e, B f, from the extremities of the object, if the mirror were not interpoſed, would converge in d; but are reflected more converging, and unite at D, and there form a larger angle, and of courſe exhibit the image a b larger than the object.

This image appears further from the back-ſide of the mirror than the object does from the fore-ſide. Let A, *fig.* 18, *pl.* 5, be a point of any object placed nearer the mirror than it's focus, and from which a cone of diverging rays proceeds; theſe will be reflected leſs diverging, and therefore have their imaginary focus *a* further off, and conſequently the image will ſeem at a greater diſtance behind the mirror, than the object is from the front of it.

But if the object be further from the mirror than F, for example, at e, *fig.* 18, *pl.* 5, the rays e b, e d, diverging but little, are reflected convergent, and exhibit the image at E; ſo that if the eye o recedes far enough to receive the diverging rays from E, it will perceive the image at E between itſelf and the mirror. The reaſon is plain; every enlightened point of an object becomes viſible by means of a cone of diverging rays proceeding therefrom; we ceaſe to ſee it if the rays become parallel or converging, which happens when the object is further from the mirror than it's focal point F; the eye therefore muſt recede, till the rays, having croſſed, become divergent.

This image is always inverted, as b a, the image of B A, *fig.* 19, *pl.* 5; for we cannot ſee the whole of an object A B, unleſs diverging rays from it's extremities fall upon the eye; and this cannot in the preſent inſtance take place till after theſe rays have croſſed between the object and mirror, by which of courſe they are inverted.

I ſhall endeavour to illuſtrate further, by a diagram, the theory of the foci of rays reflected by a ſpherical ſpeculum. Through the center O of the ſpeculum A, *fig.* 5, *pl.* 6, draw an indefinite line B D;

B D; biſect O A in F; from the points O and A, divide the lines O B, A D, into parts each equal to O F or F A, marked by the figures 1, 2, 3, 4, 5, &c. And from F, take on each ſide F 1, F $\frac{1}{2}$, F $\frac{1}{3}$, F $\frac{1}{4}$, &c. each equal to the whole, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. of F O, F A. Now, if in the line O B, the point 1 or 2, 3, 4, &c. be the focus of incident rays, the correſpondent point 1, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. in the line O F, will be the focus of the reflected rays. And *vice verſa*, if the laſt be the foci of incidence, the former will be the foci after reflection. In like manner, if 1, 2, 3, 4, &c. in the line A D be the foci of incidence, 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. will be the foci of reflected rays; and *vice verſa*: ſo that the focus of incidence and reflection unite in O and A: and their motions from O and A towards B and F in the one caſe, and towards D and F in the other, are exactly ſimilar, F being the focus of parallel rays in both caſes.

If in a dark room a lighted candle be held farther from a concave ſpeculum than it's principal focus F, as ſuppoſe at 2, it's image will be ſeen diſtinct, but inverted upon a white paper, held at the correſponding point $\frac{1}{2}$. And if the candle be moved to or from the ſpeculum, ſo as to retain the diſtinct image thereof, you will obtain an ocular proof of the theory of the foci of incident and reflected rays; when the candle is at o, the paper will be there alſo. But as the image of an object between F and a concave ſpeculum, or any where before a convex one, is on the other ſide of the ſpeculum, in either caſe, the experiment of the candle and the paper cannot take place.

The appearance of the image in the air between the mirror and the object, has been productive of many agreeable deceptions, which, when exhibited with art and an air of myſtery, have been very ſucceſsful, and a ſource of gain to many of our public *ſhowmen*. I was well pleaſed at one of theſe exhibitions, by a man in Bond-ſtreet, where a death-head and other objects were exhibited in this manner, in ſuch a way as to ſurprize the ignorant, and yet not diſguſt thoſe who were better informed.

If you place yourſelf before this concave mirror, but farther from it than the focus, you will ſee an inverted image of yourſelf in the air between you and the mirror, but you will find the image of a ſmaller ſize than yourſelf. If you hold out your hand towards the mirror, the hand of the image will come out towards your hand, and when at the center of concavity be of an equal ſize with it; and you may ſhake hands with this aerial image. If you move your hand farther, you will find the hand of the image paſs by your hand, and come between it and your body; if you move your hand towards either ſide, the hand of the image will move towards the other, the image moving always contrariwiſe to the object. All this while, thoſe who are by-ſtanders ſee nothing of the image, becauſe none of the reflected rays that form it enter their eyes. To render this effect more ſurprizing and more vivid, the mirror is often concealed in a box.

This pleaſing and ſimple experiment has been exhibited as an illuſtration of the Newtonian doctrine of ſpace. The experiment ſhews, that by an image formed in the air, at a certain diſtance between a concave ſpeculum and a perſon looking into it, *extenſion* and *form* become an *object of ſenſe*, where there exiſts neither ſolidity nor ſenſible reſiſtance. But this does not prove, that an image can be formed in a vacuum, in empty ſpace, or where there is no matter, unleſs it can firſt be proved, *that there can be no matter where we are not ſenſible of reſiſtance*. For on the contrary, it may be inferred from this phenomenon, that thoſe ſpaces, which in a looſe and incorrect ſenſe we call *empty*, are as *full* of matter as thoſe in which we find the moſt ſolid matter: for as our corporeal ſenſes can be only affected by matter, they are certainly infallible ſtandards for determining where matter is; ſo that you may be as aſſured of a fullneſs of matter, where you *ſee* any thing though you cannot *feel* it, as you would be certain there was matter where you *felt* it, though you could not *ſee* it, or though it were of the nature of that matter to be inviſible. All kinds of *reflected images* ſhew, that wherever an object can be formed to impreſs the ſenſes of ſight, there muſt be as great a fullneſs of matter as in the original object, from whence the image was carried to thoſe ſpaces where it is again renewed.

Mr. Ferguſon mentions two pleaſing experiments to be made with a concave mirror, which you may take an opportunity of trying at leiſure. If a fire be made in a large room, and a ſmooth mahogany table be placed at a good diſtance near the wall, before a large concave mirror, ſo that the light of the fire may be reflected from the mirror to it's focus upon the table; if you ſtand by the table, you will ſee nothing but a longiſh beam of light; but if you ſtand at ſome diſtance, as towards the fire, you will ſee an image of the fire on the table, large and erect: and if another perſon, who knows nothing of the matter before hand, ſhould chance to come into the room, he would be ſtartled at the appearance, for the table would ſeem to be on fire, and by being near the wainſcot, endanger the whole houſe. There ſhould be no light in the room but what proceeds from the fire.

If the fire be darkened by a ſcreen, and a large candle be placed at the back of the ſcreen, a perſon ſtanding by the candle will ſee the appearance of a fine large ſtar or rather planet upon the table, as large as Venus or Jupiter; and if a ſmall wax taper be placed near the candle, it will appear as a ſatellite to the candle; if the taper be moved round the candle, the ſatellite will go round the planet. Numerous and aſtoniſhing are the phenomena that may be produced by concave mirrors: one or two more I ſhall exhibit, your own ingenuity will enable you to vary them.

Stand up on this ſtool, and tell me what you ſee on the pot near the partition. A bunch of flowers. Put out your hand, and lay hold of them; They have evaded your endeavours, and you find that you attempted to graſp a ſhadow. The ſenſe of ſight is certainly ſubject to the greateſt illuſion, and this experiment is one among many inſtances. To explain the myſtery, go behind the partition, and you will find that I have placed a mirror exactly facing the hole in the partition. There is alſo an Argand's lamp, ſo placed as to throw a ſtrong light on the object, without throwing one on the mirror. The bunch of flowers is ſituated beneath the aperture in the partition, but inverted ſo as to receive the light from the lamp. The ſpace between the back part of the partition is painted black to prevent any reflection of light from falling on the mirror. The reſt is exactly ſimilar to what you have already ſeen, and what has been already explained.

Take a glaſs bottle, fill it partly with water, and cork it in the common manner; place this bottle oppoſite a concave mirror, and beyond it's focus that it may appear reverſed; then place yourſelf ſtill farther diſtant than the bottle, and it will be ſeen in the air inverted, and the water which is actually in the lower part of the bottle will appear to be in the upper.

If you invert the bottle while before the mirror, the image will appear in it's natural erect poſition, and the water will appear in the lower part of the bottle: while it is in this inverted ſtate, uncork the bottle, and while the water is running out, the image is filling; but as ſoon as the bottle is empty, the illuſion ceaſes. If the bottle likewiſe be quite full, there is no illuſion. The remarkable circumſtances in this experiment are, 1. Not only to ſee an object where it is not, but alſo where it's image is not. 2. That of two objects which are really in the ſame place, as the ſurface of the bottle and the water it contains, the one is ſeen in one place, the other in another, &c. It is ſuppoſed that this illuſion ariſes partly from our not being accuſtomed to ſee water ſuſpended in a bottle with the neck downward, and partly from the reſemblance there is between the colour of air and the water.

As parallel rays which fall on a concave mirror are reflected ſo as to unite at a focus; and as the ſun is ſo remote, that the rays of each beam may be conſidered as parallel, they will converge to the principal focus of the mirror, and the heat produced by this means will be ſufficient to ſet fire to ſuch bodies as are placed before the mirror at the principal focal diſtance, that is, half a ſemidiameter of the mirror's concavity. The different degrees of heat at the focus of different concave mirrors, is eſtimated in the ſame manner as we have already eſtimated the power at the focus of a convex lens.

The ancients made uſe of concave mirrors to rekindle the veſtal fires. Plutarch, in his life of Numa, ſays that the inſtruments uſed for this purpoſe, were diſhes, which were placed oppoſite to the ſun, and the combuſtible matter placed in the center, by which it is probable he meant the focus, conceiving that to be at the center of the mirror's concavity.

You have, no doubt, long ſince perceived that there is a great reſemblance between the properties of *convex lenſes* and *concave mirrors*. Convex lenſes and concave mirrors form an inverted focal image of any remote object by the convergence of the pencil of rays.

Concave lenſes and *convex mirrors* have alſo conſiderable reſemblance in their properties; they in general form an erect image in the virtual focus, by the divergence of the pencil of rays.

In thoſe inſtruments, as teleſcopes, whoſe performances are the effects of reflection, the concave mirror is ſubſtituted in the place of the convex lens, and the convex mirror may be uſed inſtead of the concave lens; but their diſpoſitions with reſpect to each other muſt neceſſarily differ from thoſe of lenſes, on account of the opacity of the one, and the tranſparency of the other.

The following curious experiments by Mr. King,* are too important to be paſſed over; beſides which, they have an intimate relation to ſome of the ſubjects already treated. Mr. K. placed a common ſize candle at the diſtance of ſix feet from a concave glaſs mirror, two feet and an half in diameter; and at the diſtance of ſeventeen feet three inches, he placed a ſecond glaſs mirror, two feet diameter; and in the focus of this glaſs, at two feet ſix inches, he placed the bulb of a thermometer, graduated with Fahrenheit's ſcale. In five minutes the quickſilver in the thermometer, though at 25 feet 9 inches from the candle, roſe 8 degrees, namely, from 60 to 68; on being removed from the focus, it fell again to 6. That it's riſe was not occaſioned by any additional warmth in the room was certain, becauſe another thermometer which was in the room did not riſe at all in the interval. The alteration of the height of the quickſilver was therefore ſolely owing to the concentration and convergency of the rays of the light of the candle at the focus.

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* See Morſels of Criticiſm, by E. King, Eſq.

He then removed the candle, and, under the ſame circumſtances, placed a little wire grate 4 inches in diameter, containing 3 pieces of lighted charcoal, and cauſing them to burn bright by blowing a common pair of bellows, the thermometer was again placed in the focus; in ſix minutes it roſe 19 degrees, from 60 to 79, although the heat of the room was no way increaſed by the experiment, as it was very large. One remarkable circumſtance attended this experiment, which was, that there was very ſenſibly to be perceived a ſmall increaſe of heat the whole way from the ſurface of the ſecond mirror to the focus; whereas when the rays of the ſun are made uſe of, no ſuch increaſe of heat at all is ever perceived within the conical convergency.

After making ſeveral ſimilar experiments, all of which concurred in proving that the effect was produced by the rays of light and heat from the ignited bodies, Mr. K. placed a tea urn of boiling water in the place of the charcoal, at the diſtance of 6 feet from the firſt mirror, and placing the thermometer in the focus of the ſecond mirror, in the ſpace of five minutes the quickſilver roſe *one* degree, which was even more than could be expected; in the next five minutes, the thermometer advanced one degree more, and yet the other thermometer in the room remained ſtationary; in another five minutes, the ſteam cooling, the thermometer began to deſcend, and in five minutes more the quickſilver fell one degree.

The reſult of theſe experiments is clear and obvious: That fire is in a degree ſubject to the ſame kind of *reflexibility* and *refrangibility* * with the rays of light.

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* For a convex lens interpoſed between the mirror and the focus, augmented the effect of heat.

If a luminous body be placed in the focus of a concave mirror, it's rays will be reflected in parallel lines, and will therefore ſtrongly enlighten, at a great diſtance, a ſpace of the ſame dimenſion with the mirror. If the luminous object be placed nearer than the focus, it's rays will diverge, and conſequently enlighten a larger ſpace. It is on this principle that reverberators are conſtructed.

But few articles on this ſubject remain to be diſcuſſed. I have only to ſhew you how to find the principal focus of theſe mirrors, and then give you a conciſe view of the properties we have already inveſtigated, and an explanation of the various phenomena of pictures viewed in a concave ſpeculum.

TO FIND THE FOCAL LENGTH OF A SPHERICAL SPECULUM.

1ſt. For a Concave Speculum.

Place the ſpeculum ſo that it's axis may be nearly towards the center of the ſun. If the ſpeculum be concave, find the burning point, or receive the image upon a white piece of paper; and the diſtance between the focus ſo found, and the vertex of the ſpeculum, is the focal length. Or, cover the ſpeculum with a ſheet of opake paper, in which make two or more holes, and obſerve where the beams of light reflected from theſe holes unite, and this will be the focal diſtance. Or, laſtly, place the ſpeculum at the end of a long table, in a vertical poſition; place a candle at the oppoſite end of the table, ſo that it's flame may be oppoſite to the vertex of the ſpeculum; then take a piece of white paper, and having fixed it to a ſtick, place the ſtick in the ſocket of a candleſtick, ſo that the paper may be ſupported at about the ſame height with the candle; then move the paper or the candle to and fro, till the image of the candle on the paper is exactly over the candle itſelf, and the point of coincidence is the center of the ſpeculum.

2. *For a Convex Speculum.*

Stick two round opake patches thereon, and hold a white paper parallel to the ſpeculum, and obſerve where the ſhades of the patches fall upon it, as at G, H, *fig.* 1, *pl.* 6; meaſure exactly the diſtance AG, and the diſtance betwixt the centers of the ſhades G, H, and between the centers of the patches; then GH—AD(=e H) to AD, ſo is AG (=De) to AF, the diſtance required.

Or, cover it with paper, having two pin holes made, one near each edge of the mirror; expoſe it to the ſun, holding another paper before it, having a hole large enough to let the ſolar rays paſs through to the two pin holes. You will ſee two white ſpots of reflected light on each ſide the hole; move the paper backward and forward, till the diſtance of the ſpots be twice the diſtance of the holes in the cover, and that diſtance of the paper from the lens is the principal focus.

GENERAL PROPERTIES OF SPECULUMS.

To ſee the image of an object made by any ſpherical ſpeculum, the eye muſt be placed in the diverging rays, facing the image, and at a proper diſtance for diſtinct viſion.

If the eye be placed near the ſpeculum, in the converging rays before they reach the image, it will perceive the image of the object beyond the glaſs, and at the ſame diſtance nearly as the object is before it, and of the ſame magnitude.

If an image be viewed with both eyes, placed very near the image, and in the diverging rays;

either it will not be ſeen at all, or it will appear double; for the axes of the eyes cannot both be directed to an object extremely near.

Though an eye cannot ſee an image in the air, except it be placed in the diverging rays; yet if that image be received on a white paper, it may be ſeen in any poſition of the eye. For the rays reflected from the mirror to the image and beyond, flow but in that one direction; but when the image is received on white paper, the rays are reflected in every direction.

If the eye be moved whilſt it views the image, the image will appear to be moved; for rays will come ſucceſſively to the eye from different points of the ſpeculum.

If an *object be placed in the principal focus* of a concave ſpeculum, it's apparent magnitude to the eye, at any place whatſoever, will be invariably the ſame, and equal to the apparent magnitude to the naked eye, when ſeen from the center of the ſpeculum. Conſequently the apparent magnitude of an object placed in the principal focus, will always continue the ſame, however the eye is moved backward or forward from the ſpeculum.

The nearer the eye is to the ſpeculum, the more of the object appears, and *vice verſa*.

If the object be nearer than the principal focus, it's apparent magnitude grows leſs in going from the ſpeculum; if it be further off, it increaſes.

The apparent magnitude of an object will be invariable wherever it be placed, *if the eye be at the principal focus.*

When the eye is at a leſs diſtance than the principal focus, the magnitude of the object decreaſes as it is moved from the ſpeculum.

When the eye is fixed at a greater diſtance than this focus, the apparent magnitude of an object increaſes in going from the ſpeculum till it arrives at the conjugate focus; then it is all confuſion. Afterwards it diminiſhes again, and is inverted.

A face in going from a concave decreaſes to the principal focus, and then increaſes.

OF PICTURES SEEN IN A CONCAVE SPECULUM.

If a picture, drawn according to the rules of perſpective, be placed before a concave ſpeculum, a little nearer than it's principal focus, the image of the picture will appear extremely natural, and very nearly like the real one from whence it was taken. For not only the objects are greatly magnified, ſo as to approach nearer their natural ſize; but they have alſo different apparent diſtances, inſomuch, that a view of the inſide of a church appears very like a real church; and landſcape pictures as the real objects would do, ſeen from the ſpot where the view was taken.

This curious phenomenon will be in a great meaſure accounted for, by attending to this diagram, *fig.* 3, *pl.* 6. Where the curve p q r is the geometrical image of the ſtrait object P Q R, or that curve which contains the foci of all the pencils of light that diverge from P R, and whoſe axes paſs through the center o of the ſpeculum B A C, after their reflection by that ſpeculum. Now it is proved by geometry, that the geometrical image of a circle facing the ſpeculum, and whoſe center is at Q, and whoſe diameter is P R, will be a hollow figure, formed by the rotation of the curve p q r, round the axis O q. If this hollow figure is ſuppoſed to be a real thing, whoſe inſide ſurface is variouſly diſtinguiſhed into parts by different colours, and a picture of it be drawn upon the circle P R, the point of ſight being at O; a ſpectator placed at o, would be affected much

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in the ſame manner, by rays coming to him from the picture, after reflection by the ſpeculum, as he would by rays coming to him directly from the hollow figure, the ſpeculum and the picture being removed; for in this caſe, *the hollow figure, and the geometrical image of the picture upon the circle, are both coincident.*

Again, the geometrical image of a rectangular parallelogram A B, *fig.* 4, *pl.* 6, placed where P Q R is, *fig.* 3, will be alſo a hollow figure; but more like a pyramid with four ſides, than to the figure deſcribed by the rotation of the curve p q r. In like manner a leſſer parallelogram within the former will have the image of it's ſides like thoſe of the former, but at a greater diſtance; and ſo likewiſe the ſides of the ſeveral parallelograms c d, e f, &c. will have their images in a ſeries one behind the other, the middlemoſt being fartheſt of all; ſo that the geometrical image of the whole figure does ſomewhat reſemble the fruſtrum of a hollow pyramid with four ſides, and which, on account of the greater apparent diſtance of the ſmaller or middle parts, appears nearly like a hollow priſm, a ſection of which is p s t r.

Now if p s, or r t, be the length, and s t, or p r, the breadth of the inſide of a church, a perſpective view of which, from O, is drawn upon the plane PR, the geometrical figure will not be very unlike the church itſelf. For the picture upon the plane P R, is a figure properly conſiſting of ſeveral parallelograms diminiſhing towards the middle, after the manner of thoſe above deſcribed; and if the picture be not too large in proportion to the ſize of the ſpeculum, the curvities ariſing from the form of the ſpeculum, will not be very conſiderable. But as moſt of the pencils of light entering the eye, diverge from points that are at great diſtances, their different divergencies are not alone ſufficient for determining the true place of their foci: and the apparent image of a blank ſurface placed at PR, will not appear near ſo concave as the geometrical image.

Here, however, we muſt have recourſe to ſome other cauſe, and we ſhall find many concurring ones. The contiguous parts of the picture of the floor, for inſtance, form a long ſeries of viſible images, contiguous likewiſe to one another. The images of the remoter parts appear alſo at the ſame time fainter and ſmaller, becauſe the pictures of the remoter parts of the real floor diminiſh faſter in proportion, than the apparent diſtances of the images of the pictures increaſe; ſo that from all theſe cauſes conſpiring together, the eye receives much the ſame impreſſion as if it looked at a real floor; in both caſes, the appearance is much the ſame; a long extended ſurface, a little diminiſhed in breadth, and that gradually, towards the farther end. In like manner the walls appear erect and extended on each ſide, and the roof above facing the pavement; and all gradually inclining, after the ſame manner as a large room appears to the naked ſight when viewed from one end. Beſides the above helps, the window-lights in the ſides, the ſhades of upright objects thrown upon the pavement, &c. in the pictures, do alſo contribute their ſhare; and all conſpiring together, do ſufficiently outweigh the imperfections of the geometrical image. So that inſtead of a diſtorted picture, we ſee in a manner a real church; the great magnitude of the whole, it's viſible concavity, and proportionable length and diſtance of parts, all contributing powerfully to excite this idea. Landſcapes, &c. are in like manner ſurprizingly improved by a concave ſpeculum.

Theſe phenomena appear rather more perfect to both eyes than to one alone; and the appearance will be the ſame to one who does not know what the picture on the paper repreſents, which proves that the ſaid phenomena are not founded upon mere prejudice. A young child, who had never ſeen any thing like what was repreſented, ſhews great marks of joy and ſurprize upon looking at a print in a concave ſpeculum. If it can be ſaid that nature is any where improved upon, I think this is the place: for if the print or picture be finely executed, the opportunity we have of viewing it's image without any extraneous light intruding into the eye, is an advantage we cannot have when we look at remote objects, and is productive of a wonderful effect.

OF VISION BY LIGHT REFLECTED AT A CONVEX SPECULUM.

We have very little to add to what we have already ſaid on this ſubject. In a convex ſpeculum, the images of objects are always ſeen erect, a little convexed towards the eye, and diminiſhed, yet pretty nigh to the ſpeculum; and the greater the convexity, the nearer, the ſmaller, and the more convex will the images of objects be.

If the ſpeculum be a pretty large ſegment, it will exhibit the images of the objects that are pretty wide aſunder; ſo that part of the cieling, floor, and two ſides of the room, may be ſeen at the ſame time, the whole making a kind of picture very agreeable in it's effect: and the nearer the eye is to the ſpeculum, the larger will be the field of the viſible images. *The appearance is a kind of mean between the objects themſelves and a good picture of them on a flat ſurface; and upon this account, and alſo for grouping the objects, a convex ſpeculum may be very uſeful to a landſcape painter.*

If, while the objects and ſpeculum remain fixed, you move to or from the ſpeculum, the apparent places and magnitudes of the images will remain invariable: but if an object moves to or from the ſpeculum, it's images will alſo appear to move the contrary way; and as it approaches nearer orrecedes farther, it will appear more and more enlarged or diminiſhed.

If a convex mirror be placed againſt a window having an extenſive proſpect, or facing the end of a ſtreet, the great multiplicity of objects that are ſeen one behind the other, and the diminution of their images, will ſometimes, after poring into the ſpeculum, make us fancy they are a great way off; and, perhaps, further than the objects themſelves. But on looking more attentively, this miſtake will be corrected, and the apparent places of the images will not differ ſenſibly from their real places, or thoſe places whence the the rays diverge to the eye.

OF VISION BY PLANE SPECULUMS.

We have already explained to you the abſtract theory of images formed by the reflection and refraction of plane and ſpherical mirrors; I ſhall now conſider the phenomena of viſion by plane mirrors.

Objects, as we have obſerved, ſeen by reflection of plane ſpeculums, generally appear ſo perfect and natural, that if the ſpeculum itſelf is not perceived, we are liable to miſtake the images for the real objects of which they are the types. A man appears alive, corporeal, and not a mere ſurface; and any ſeries of objects placed before the ſpeculum exhibit alike ſeries on the other ſide, all appearing in their due places, agreeable to the theory of images and of viſion; with this difference, that the images appear ſomewhat darker than the objects, on account of the loſs of light by reflection; and this, when the images are remote, will affect their apparent diſtances; and more eſpecially if, as the caſe often is, part of the floor ſuſtaining the real objects is not ſeen, or if the ſpeculum is not vertical. But when the images are near, theſe cauſes have no ſenſible effect.

When you ſee your own image, or that of an object behind you, in the ſpeculum, if the image be erect, it will appear inverted as to right and left; and the reaſon is, becauſe the object and the image face each other, or look contrariwiſe. The caſe is not unlike, when the object is between us and the ſpeculum, though we are apt to make it different for want of conſidering that it is the back of that towards us, and ſo call that the right ſide of the object, which we ſhould call the left, if we were on the other ſide. The phenomena of viſion in plane ſpeculums agree ſo well with the theory of images, that we need ſay nothing more on this head, but proceed to explain the phenomena, when two or more ſpeculums are combined together, or when one is placed in an inclined ſituation.

If a plane mirror be inclined to the horizon in an angle of 45 degrees, with it's face downwards, an upright object will have it's image in an horizontal poſition, and the image of an object lying horizontal will be erect.

If A B, *fig.* 6, *pl.* 6, be a plane looking-glaſs, with it's reflecting ſurface downwards, and C D be an object parallel to the horizon, then the mirror A B, which makes half a right angle will make half a right angle with the object; or A B C will be an angle of 45°. Now, at whatever diſtance a point C, in the object is from the mirror, the correſpondent c, in the image will appear at the ſame diſtance from the mirror on the other ſide; therefore C E will be equal to c E: for the ſame reaſon any other point D, will be juſt as far diſtant before the mirror as it's correſpondent point d is behind it; ſo that as the object forms an angle of 45° on one ſide of the mirror, the image will form alſo an angle (from the ſame angular point) of 45° on the other, 45 added to 45 making 90°, or a right angle, ſo that the image is perpendicular to the object, and being therefore perpendicular to the horizon will appear erect. For the ſame reaſon, an upright object will have it's image in an horizontal poſition; conſequently if you ſtand upright before a mirror inclined to the horizon, the face upwards, you will ſee your image extended horizontally, as it were, on the floor, with your face upwards.

Hence, if you look into a plane ſpeculum, inclined to the horizon in an angle of 45°, but with the face downwards, you will ſee yourſelf as it were in a flying poſture; you will ſeem to be ſuſpended horizontally in the air with your face downwards; and if the ſpeculum is ſufficiently long, you will ſeem to fly upwards or downwards, as you walk to or from the ſpeculum.

If the ſpeculum be inclined in any other angle, the angle of the image will be varied in the ſame manner: theſe poſitions you may eaſily verify by means of a common dreſſing-glaſs, as the inclination thereof may be altered at pleaſure.

On theſe principles is conſtructed an optical deception, which Dr. Hooper has named the *animated optic balls*. On a flat board a ſerpentine groove is formed in ſuch manner, that if the board be inclined, and a ſmall ivory ball be placed at the top of the uppermoſt groove, it will roll with the ſame velocity till it gets to the bottom. This board is placed in a box in which there is a looking-glaſs ſo inclined that the board appears vertical, and the lower end uppermoſt; conſequently the ball will ſeem to roll upwards. When this experiment is made to be exhibited in public, every thing is contrived to conceal the principle, and heighten the deception.

In any number of plane ſpeculums, all lying in the ſame plane, there can be ſeen, from the ſame place, only one image of the ſame object. For let there be ever ſo many, they have only the effect of one mirror, and the object is ſeen by rays proceeding therefrom to the eye.

If an eye is at I, fig. 7, pl. 6, *within the angle* A B C, *formed by two plane mirrors* A B, B C, *it will ſee as many images of an object* O, *placed alſo within this angle, as you can let fall perpendiculars ſucceſſively on the mirror from the object and each of the images.*

1. Let fall the perpendicular O D, on the mirror B C; make N D equal to N O, and the point D will be the place of the image: for if you draw I D from the eye, and from g, where it meets the mirror, draw g o, you will find the angle of incidence O g N equal to the angle B g I.

2. If from the point D you let fall on the mirror A B, the perpendicular D E, and make k E =k D, the point E will, for the ſame reaſons, be the place of the ſecond image, whoſe object is D.

3. If from E you let fall on the mirror B C, a perpendicular E Q, and make Q F equal to E Q, F will be the place of the third image, of which E is the object.

4. If from F a perpendicular is let fall on A B, it will paſs beyond B to F G, beyond the limits of the mirrors.

In the ſame manner you may ſhew that there is in H, an image of the object O, ſeen by the ray I h, reflected by the incident ray O h; and a ſecond in K, ſeen by the ray c I, reflected from c t, reflected from the incident ray O t, that there is a third in L, ſeen by the incident ray O l, reflected in l a, and then in a k, and afterwards in k I; and that there can be no more, becauſe the perpendicular L M, from the laſt image, falls without the mirror.

From the figure you will ſee, that the firſt image is ſeen by one reflected ray; the ſecond by two; the third by three; and ſo on.

The diſtance of each image from the eye is equal to it's incident ray, added to the ſum of it's reflected ray.

The firſt image is brighter than the ſecond, the ſecond than the third; and ſo of the reſt: for the intenſity of the light is continualy diminiſhed, a conſiderable quantity being loſt at every reflection.

The larger the angle formed by the mirrors, the fewer the number of images; for the cathetus of incidence, ſeparate from each other by an angular motion, equal to that with which the mirrors are ſeparated, and are conſequently carried nearer and nearer to the angular, and fall ſucceſſively beyond it; ſo that when the mirrors form a right angle, there can be but two images, and when it is very obtuſe, there can be but one; the number of perpendiculars that can be let fall from the object or the images of the object on the two mirrors.

If the two mirrors are parallel, and infinitely extended, there would be an infinite number of images; but as they go on, their diſtance is greater, and their brightneſs leſs; they therefore ſoon become inſenſible. So that if two plane mirrors be placed parallel to each other, there will be a ſeries of images of the floor or ſpace between them, indefinitely extended both ways; there being no other limitation of their number than what is cauſed by the decreaſe of light from the continued reflections. If you ſtand between two ſuch mirrors, you will ſee in that fronting you, the images both of your fore and back part repeated ſeveral times, but continually fainter the farther off.

On this principle are conſtructed a variety of ingenious recreations; particularly thoſe that are termed *the boundleſs gallery, the magical mirrors.*

The firſt of theſe conſiſts of a long box, furniſhed at each end with a mirror, placed directly oppoſite to each other; a ſmall quantity of quickſilver is taken off from one of them, in order that you may view theſe in the inſide of the box; two or three painted ſcenes are placed in the box, and the top is covered with gauze. The ſcenes being painted on both ſides, are ſucceſſively reflected from one mirror to the other: if, for example, the painting conſiſts of trees, they will appear like a very long viſta, of which the eye cannot diſcern the end; for each mirror repeating the objects continually more faintly, contribute greatly to augment the illuſion.

The other conſiſts of a ſquare box, with four plane mirrors placed perpendicular to the bottom of the box, certain objects in relief are placed on the bottom, and the top covered with gauze placed ſloping-wiſe like the roof of an houſe, leaving only an aperture at the top for the eye. When you look in the box, you will find that the mirrors, from being oppoſed to each other, mutually reflect the incloſed figures; the eye beholds a boundleſs extent completely covered with theſe objects, and if they are properly diſpoſed, the illuſion will occaſion no ſmall ſurpriſe, and afford great entertainment.

In a ſingle plane mirror, that is made of thick glaſs with quickſilver behind it, many images of any bright object, as a candle, may be ſeen.

The firſt ſurface of the glaſs being ſolid and poliſhed, is itſelf a mirror, which ſends back all the rays which do not traverſe the glaſs, and thus forms a weak image of the object. By looking at a candle obliquely in a mirror, you will ſee very evidently, by it's exhibiting a ſeries of images, that the rays of light are reflected ſeveral times between it's ſurfaces: the images, however, all decreaſe in brightneſs, till at laſt the rays become too faint to exhibit an image. Theſe are more diſtinguiſhable, the more obliquely they are viewed. This phenomenon proves very plainly, that light ſuffers a conſiderable diminution in it's paſſage through glaſs.

If a plane mirror turns upon an axis, the angular motion of the images is double that of the mirror.

Let A B, *fig.* 2, *pl.* 6, be a mirror, O E an incident ray, E F a reflected ray. Now ſuppoſe the mirror to turn upon an axis at E, and to take the ſituation C D, then the incident O E will have G E for it's reflected ray. Now the angle F E G, which expreſſes the angular motion or quantity, that the reflected ray has moved from it's firſt ſituation F E, is double of A E C, the angular motion of the mirror. If, therefore, the mirror moves one quarter of a circle, the reflected ray moves a half circle: it is for this reaſon that the images of the ſun, by a mirror, move ſo faſt; and hence, alſo, the images thereof reflected by water, even nearly quiet, appear much agitated, particularly when received at ſome diſtance from the point of incidence.

To judge of the goodneſs of plane mirrors. Having endeavoured to explain the principle of the phenomena of plane mirrors, I ſhall now proceed to ſuch obſervations as may enable you to judge of their goodneſs. A ſpeculum ſhould be exactly figured and well poliſhed. The goodneſs of the figure of a plane ſpeculum is eaſily known, by obſerving if images ſeen in all poſitions, eſpecially in very oblique ones, and from all parts of the ſpeculum, appear exactly equal, and ſimilar to the objects: that is, if the images, eſpecially the remoteſt objects in the room, appear natural, without having any part of them diſtorted, the ſpeculum has a good figure. The ſtrait edges of the rails of wainſcot are good objects for the experiment. A plane muſt be exceedingly erroneous, that will diſtort a face looking into it, becauſe the rays being returned almoſt directly back to the eye, ſmall aberrations cannot be ſenſible: But if two perſons look at each other's image as obliquely as they can, they will ſoon perceive if the ſpeculum be faulty.

It is deemed a very difficult thing to grind a *true plane*; and the difficulty of making a good looking-glaſs is ſtill greater, becauſe the two ſides ſhould be exactly parallel as well as flat. If the images of a candle ſeen very obliquely, and in different obliquities, and from all parts of the glaſs, do not always keep pretty nearly at equal diſtances one from another; it is a proof that the ſides of the glaſs are neither flat nor parallel.

The better a ſpeculum is poliſhed, the brighter will be the images; that is, the eye will receive more light from it. The darker the colour of a glaſs ſpeculum, the higher is the poliſh. Different glaſſes, though equally well poliſhed, will not always appear equally dark; yet generally the above rule takes place, and the darkeſt is to be preferred.

LECTURE XVII.

ON THE NATURE OF VISION.

IT has been my endeavour, in the preceding Lectures, to reſcue Philoſophy from the imputation ſhe has long lain under of being dangerous to religion and piety. It was not uncommon formerly to ſuſpect every one who profeſſed to purſue the light of nature, of unſoundneſs of principles, and of a ſecret deſign to undermine the belief of a Providence, and the being of a God. Nor can it be denied, that there has been ground for ſuch a ſuſpicion; for thoſe who really had ſuch evil deſigns, proceeded by attempting to explain the ſurrounding phenomena by the powers of nature, and thus endeavouring to confine the attention of mankind to them alone. But the ſtate of natural philoſophy is now altered; it is become an innocent, inoffenſive ſcience, a uſeful miniſter in the temple of the LORD.

In ancient times, nature was eſteemed an original ſource of being, diſtinct from the ALMIGHTY; matter was thought to be poſſeſſed of a being which HE never gave it, and the elements to have their differences and qualities independent of *him*. Theſe notions have long ſince been exploded, and GOD is acknowledged to be the *creator* of all things viſible and inviſible. It is now clear, that the abſtract and ſenſible eſſences of nature receive their permanency, and her courſes their ſtability, from the covenant or immutable will of GOD; her ſubſtances, both material and ſpiritual, together with their primary as well as ſecondary qualities; their applications to one another; their mutual affections, and all effects and events reſulting therefrom, being derived primarily from no other ſource, than the *power*, the *wiſdom*,

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and the *goodneſs* of GOD. Nature is the work of GOD, her acts are his acts, her productions his gifts, her every operation an execution of his will. "Great, then, is the error of thoſe who have ſet up *nature* as a firſt principle, in the place of GOD, whereby to account for phyſical operations and productions; for nature is nothing in itſelf, but a mere word without any meaning or idea belonging to it, if conſidered in any other view than as that ſyſtem of laws whereby God upholds this viſible world, and produces the infinite variety of forms and effects in it, according to an eſtabliſhed and regular courſe of ſubordinate cauſes and means; and conſequently, where the mind terminates it's views in a ſuppoſed nature as a ſelf-moving agent or principle, it robs GOD of the honour due to his majeſty, and transfers it to an *idol* of it's own making."

The ſtudy of the human frame, &c. has been regarded with the ſame unfavourable ſuſpicion as philoſophy. For there being a great deal of mechaniſm in the human compoſition, thoſe who applied to a cloſe examination and ſtudy of the machine, were apt to think too ſlightly of the ſpiritual part, inſomuch, that it has been a current ſaying, wherever you ſee three phyſicians, you ſee two atheiſts. But I do not apprehend that they now retain the ſame ſentiments. They erred, becauſe they ſaw that the underſtanding might ſometimes be reſtored to madmen by medicines: they knew that ſome of their drugs had a powerful effect upon the imagination, ſo as to warm it with ſanguine hope, or chill it with deſponding melancholy: they found that a delicacy of texture in the fibres of the brain, a purity of the circulating juices, had an influence on the natural talents, and occaſioned a predominancy of ſome one of the principal humours that diſtinguiſhed the characters of men;

that an unnatural preſſure, or a little heterogeneous mixture in the medullary ſubſtance within the head, diſabled the ſoul from exerciſing her functions; and that in general the tenour and colour of our thoughts depended very much upon the diſpoſition of the body. Arguing from *appearances,* which will ever miſlead, they imagined that powers had been aſcribed to the ſoul, which really reſided in the body, and were tempted in an evil hour too haſtily to conclude, that ſhe had none belonging to her; but that thought itſelf, with all it's varieties, were nothing more than mere configuration and a diverſity of motions in matter.

" Beginning at the wrong end, and tracing the intellectual operations from organized matter as their ſource and cauſe; they could not but infer, that the cauſe being taken away, the effect muſt neceſſarily ceaſe. Seeing that a contuſion, or other injury of the brain, occaſions a diſorder or loſs of the underſtanding and memory, they thence argued that the brain is the principal cauſe or foundation of theſe powers; whereas perception, thought, and memory, do not flow from the brain, but from the *mind* into it, as the proper medium for the manifeſtation of the intellectual powers. The defect or deſtruction of the organ does not occaſion any abſolute loſs or annihilation of intellect, for that ſtill remains the ſame in it's own ſpiritual principle, it only hinders it from manifeſting it's operations in the natural world." To ſuppoſe that *mind* and *matter* are the ſame, becauſe the diſorder of the body apparently influences the ſoul, is as abſurd as to ſay that the *art, ſcience,* and *intelligence* of a muſician, lies entirely in the ſtrings or pipes of his inſtrument, becauſe his knowledge is more or leſs conſpicuous, according as they are more or leſs tuned. It is a ſophiſtry that can only dazzle ſuperficial minds, that thus take appearances for realities, effects for cauſes.

But this temptation is now removed; for a more exact ſcrutiny into the properties of matter has clearly ſhewn, that no aſſortment of matter, how nicely ſoever arranged, can form an intelligent being. Let materialiſts inſiſt as ſtrongly as they pleaſe, that the characters and thoughts of men reſult from their machinery and organization; we know that no ſuch reſult could take place, unleſs there were a *perceptive ſpirit* to receive the action of the machine. To imagine otherwiſe would be as abſurd as to ſuppoſe that a bible might teach a ſentiment of religion without a reader to peruſe it, or the graſs a ſenſation of green, without an eye to diſcern it. Some things, indeed, the *mind* performs through the *body*; as for example, the various works and energies of art. Others it performs without ſuch a medium, as when it thinks, and reaſons, and concludes. Now, though the mind, in either caſe, may be called the principal ſource, yet theſe laſt are moſt properly it's own peculiar acts, as more immediately referable to it's peculiar powers; and thus is mind ultimately the cauſe of all.

"The ancient *atheiſts*, as Anaximander, Democritus, &c. founded their tenets on the hypotheſis of matter being the firſt and only principle, to the excluſion of all ſpiritual ſubſtances. Their followers in infidelity, in modern times, have done the ſame: nor, indeed, is there any other ſuppoſition, weak as it is, on which the ſyſtem of atheiſm can be raiſed."

"That the abſurdities of a doctrine, which baniſhed all wiſe deſigns and final cauſes from the creation and government of the world, might not, by unſupported aſſertions, ſhock the common ſenſe of mankind, the authors and abettors of this impious ſcheme employed their invention to form theories to account for effects without cauſes, or at leaſt, without adequate cauſes; as by maintaining the eternity of the world in it's preſent form; or advancing, at leaſt, an eternity of atoms, which, by the direction of chance, and a lucky jumble, formed themſelves into the preſent orderly ſyſtem."

"But as they were equally puzzled to account for life, conſciouſneſs, and intellect, upon their corpuſcular plan, they found themſelves under the neceſſity of aſcribing to matter, under particular modifications, certain active powers, which are abſolutely inconſiſtent with it's known eſſential properties, affirming the ſoul to be nothing more than a mere refined and delicate configuration of atoms, and the mental operations to proceed from the mechanical motions of rarified matter: thus making the principles of life and underſtanding to be only the modes of that which has nothing vital or intelligent in it, and thus *aſcribing more to the effect than is in the cauſe to give.* Theſe complicated abſurdities have been ſo thoroughly detected and confuted, that atheiſm, as a ſyſtem, ſcarce lifts up it's head, but hides itſelf under falſe colours. It does not now preſent itſelf as the open, but as the whited ſepulchre; does not profeſſedly declare war againſt the majeſty and exiſtence of Almighty God, but ſlily endeavours to undermine his attributes, and by falſe reaſoning to invalidate the proofs of the immortality of the ſoul."

Some philoſophers among the ancients, as well as among the moderns, imagined that man was nothing but mere matter; but matter ſo curiouſly organized, that the impreſſion of external objects produces in it ſenſation, perception, remembrance, and all the other mental operations. This fooliſh opinion could have no other origin

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than the conſtant connection the Author of nature hath eſtabliſhed between certain impreſſions made upon our ſenſes, and our perception of the objects by which the impreſſion is made; from which they weakly inferred, that thoſe impreſſions were the proper efficient cauſes of the correſponding perception.*

But no reaſoning can be more fallacious than this; that becauſe two things are always conjoined, one muſt be the cauſe of the other. Day and night have been joined in a conſtant ſucceſſion ſince the beginning of the world: but who is ſo fooliſh as to conclude from this, that day is the cauſe of night, or night the cauſe of the following day? There is, indeed, nothing more ridiculous than to imagine, that any motion or modification of matter ſhould produce thought, and render it capable of ſenſation and knowledge. For thoſe things, which are inferior and ſecondary, can by no means be the principles or cauſes of the more excellent.

If any one ſhould relate of a teleſcope, ſo exactly made as to have the power of ſeeing; of a whiſpering-gallery, that had the power of hearing; of a cabinet ſo nicely framed as to have the power of memory; or of a machine ſo delicate, as, to feel pain when it was touched; the relation would be ſo abſurd, and ſo ſhocking to common ſenſe, that it would not find belief even among ſavages. Yet it is the ſame abſurdity to think, that the impreſſions of external objects upon the machine of our bodies, can be the real efficient cauſe of thought and perception. The moſt perfect organization is but a perfect arrangement of *material elements*, and gives but a new extrinſic relation of parts to parts, and *can never give capacities which did not before exiſt.* Nay, the very materialiſt. himſelf, with all his boaſted attachment to matter, is forced to have recourſe to *powers* which are as different from the common capacities of body, as *the ſentient ſubſtance* of the immaterialiſt is from the material element. Even the *man of matter*, when ſpeaking of *reſiſtance* in bodies, ſays, "that RESISTANCE is in moſt caſes cauſed by ſomething of *a quite different nature* from any thing MATERIAL."*

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* See Reid on the Intellectual Powers of Man, p. 34.

It is no wonder that philoſophers, whoſe ideas of *mind* and *being* are only derived from *body* and *ſenſation*, ſhould be thus inconſiſtent; for they have a ſhort method of explaining away the nature of *truth*. They reduce it to mere *opinion*, and conſider it as a factitious thing which every man makes for himſelf; which comes and goes juſt as it is remembered or forgot; which, in the order of things, makes it's appearance the *laſt* of any, being not only ſubſequent to ſenſible objects, but even to our *ſenſations*. of them.

But there are other reaſoners, who have had different notions; who repreſent truth not as the *laſt*, but the *firſt* of beings; who call it immutable, eternal, omnipreſent. To theſe it muſt appear ſomewhat ſtrange, how men ſhould imagine, that a crude account of the method *how they perceive truth*, was to paſs for an account of *truth itſelf*: as if to deſcribe the road to London, could be called a deſcription of that metropolis.

You are better learned than to conſider truth as opinion: you know that it ſhines with unchangeable ſplendor, enlightening throughout the univerſe every poſſible ſubject ſuſceptible of it's benign influence. Paſſions, and other objects, may prevent indeed it's efficacy, as clouds and vapours may obſcure the ſun; but itſelf neither admits *diminution* nor *change*, becauſe the darkneſs only reſpects particular *percipients*. Among *theſe*, therefore, you muſt look for ignorance and error, and for that *ſubordination of intelligence* which is their natural conſequence.

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* For a confutation of materialiſm, ſee Berrington's Letters on Materialiſm—Immaterialiſm Delineated—and Harris's Hermes.

From all theſe conſiderations you will, I hope, be perſuaded to flee from *materialiſm* as from the plague. It is an opinion that is inimical to virtue, that darkens the proſpects of futurity, unbinds the reins to vice, and is deſtructive of all true religion.

Having given you an account of the general theory of reflection and refraction of light, I ſhall now proceed to the theory of viſion. The ſubject is not only curious and entertaining in itſelf, but without it there is no accounting for ſeveral optical phenomena, or even underſtanding the theory of optical inſtruments, and the manner by which they extend ſo prodigiouſly the natural boundaries of viſion. It is alſo preſumed, that it can be no unpleaſing ſpeculation to obtain an idea of the ſecret mechaniſm by which the eye communicates ſo many diverſified and animated perceptions to the ſoul, and by which we are enabled to diſcover, with ſo much eaſe and rapidity, every ſurrounding object.

In the ſtructure of the eye you will find the moſt evident manifeſtations of exquiſite art and deſign, every part elegantly framed, nicely adjuſted, and commodiouſly placed, to anſwer in the moſt perfect manner every poſſible good purpoſe, and thus evince that it is the work of unerring *wiſdom*, prompted to action by infinite *love*.

So manifold are the bleſſings we derive from this organ, that the mind of man ſeems almoſt inadequate to the conception, and his pen to the deſcription of them. While it forms our ideas of magnitude and diſtance, it annihilates ſpace, by placing the neareſt and moſt diſtant objects cloſe together. To it we are indebted for the delightful ſenſations that ariſe from the proportion and variety of forms, the harmonious mixture of colours, and the graces of beauty. It enables us to ſeek, to ſee, and to chuſe our food; to go here and there, as the calls of friendſhip, or the occaſions of buſineſs, require; to traverſe the ocean, ranſack the bowels of the earth, viſit diſtant regions, accumulate wealth, and multiply knowledge. Aſſiſted by it, we become acquainted with the works of the CREATOR, and can trace his wiſdom, his power, and his goodneſs, in the texture of plants, the mechaniſm of animals, and the glories of the heavens.

The value of this ſenſe is heightened, when we conſider the miſeries attendant on the want of it; for among the numerous evils that afflict the human race, there is none more juſtly dreaded, nor more deeply deplored, than a deprivation of ſight. It is to have one of the chief inlets of happineſs cut off, to be ſhut up in perpetual darkneſs, to labour under ten thouſand inconveniences, and to be expoſed to continual dangers. How poignantly this loſs was felt by our great poet, is painfully evident from his own words:

"With the year
Seaſons return; but not to me returns
Day, or the ſweet approach of ev'n or morn,
Or ſight of vernal bloom, or ſummer's roſe,
Or flocks, or herds, or human face divine;
But cloud inſtead, and ever-during dark
Surrounds me, from the chearful rays of men
Cut off, and for the book of knowledge fair,
Preſented with an univerſal blank

Of nature's works, to me expung'd and raz'd,
And wiſdom at one entrance quite ſhut out."

A SHORT DESCRIPTION OF THE EYE.*

In deſcribing the eye, it is natural to conſider, firſt, the external parts, then the internal, or thoſe which are more immediately ſubſervient to the purpoſes of viſion.

The eye, as is well known, is ſituated below the forehead; it is placed in a bony cavity, called the *orbit*; the form is globular, it is compoſed of ſeveral coats and humours, and furniſhed with veſſels properly adapted to it's various functions.

The eye conſiſts of ſeveral *coats* or teguments, which form a *ball* perfectly globular except on the fore part, which is a little more protuberant than the reſt. Within this ball are included three different liquids or tranſparent ſubſtances, called humours.

The *orbit* of the eye is of a conical ſhape, but rather irregular in it's dimenſions; it is compoſed of ſeven bones, and lined with fat, which forms a ſoft bed for the eye to reſt on, and facilitates it's various motions. A conſiderable part of the bottom of the orbit is open for the admiſſion and tranſmiſſion of the nerves, veins, and arteries.

Thoſe prominent arches of hair, which we term the *eyebrows*, defend the eyes from the light when it is too ſtrong, and prevent their being incommoded by any ſubſtances that might ſlide down the forehead, and thence fall into the eyes. That the eyebrows may be more effectually uſeful, and form a more perfect ſcreen, they are furniſhed with muſcles to draw them down, and corrugate them; and when we are walking in a duſty road or when we are expoſed to a dazzling light, we pull down the eyebrows, and thereby ſhade the eye from the glare, and protect it from the duſt. We may gather from hence, that thoſe ſhades which encompaſs the forehead, and that project about three inches from it, are properly adapted to guard weak eyes from every offenſive glare of light.

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* What follows on this ſubject is extracted from my "Eſſay on Viſion."

The prominency of the eyebrows gives a character to the face; and hence Le Brun, in his directions to a painter, with regard to the paſſions, places in them the principal force of expreſſion. The eyebrows form a deep ſhade on the canvas, which relieves the other colours and features. A depreſſion of the eyebrow is an indication of concern and grief; whilſt an elevation thereof ſhews that the mind is either affected with joy, or enjoying the ſerene delights of tranquillity.

The *eyelids*, like two ſubſtantial curtains, protect and cover the eyes while we ſleep; when we are awake, they diffuſe, by their motion, a fluid over the eye, which cleans and poliſhes it, and thus renders it fitter for tranſmitting the rays of light.

Each eye is furniſhed with two lids, the one ſuperior, the other inferior, joining at the two extremities, which are called *canthi*, or angles. Both eyelids are lined with a membrane, which alſo infolds as much of the globe of the eye as is called the white, and it prevents any duſt, or other extraneous particles, from getting behind the eye into the orbit.

That the eyelids may ſhut with greater exactneſs, and not fall into wrinkles when they are elevated or depreſſed, each edge is ſtiffened by a cartilaginous arch. The eyelaſhes, like two paliſades of ſhort hair, proceed from theſe cartilaginous edges, warning the eye of danger, protecting it from ſtraggling motes, and warding off the wandering fly. They alſo intercept many rays proceeding from objects that are above the axis of viſion, and thereby render the images of other objects more diſtinct and lively; for, as in the camera obſcura, the image is always brighteſt when no rays are allowed to enter, but thoſe which form the picture. The eyelaſhes contribute their ſhare in giving beauty to the face, to ſoften the outlines of the eyelids, and throw a mildneſs on the features.

Both the eyelids are moveable; but the upper one moſtly ſo, the lower one moving but little, being rather obſequious to the motions of the adjacent parts, than moved by any particular forces of it's own. The hairs of the eyelaſhes grow only to a certain length, and never need cutting: the points of the ſuperior one are bent upwards, thoſe of the lower eyelaſh downwards. Thus whenever we can trace things to their final cauſe, we find them always marked with deſign, and can find no circumſtance ſo minute, as to eſcape the attention of the Supreme Being.

From what has been ſaid, we may perceive why the ſight of thoſe, whoſe eyelaſhes are black, is, in general, much ſtronger than thoſe who have them fair or white; the black eyelaſhes are a better ſhade for the eye, and reflect no light from their inner ſide, to weaken and efface the picture on the retina. *Montaltus* gives an account of a young man, whoſe eyelaſhes and eyebrows were of an intenſe white, and his ſight obſcure during the day, but clear at night. This perſon was taken priſoner by the Moors, who dyed his eyelaſhes black, by which his ſight was much ſtrengthened: in courſe of time the dye was waſhed off, and his ſight became weak again. Dr. Ruſſell, in his natural hiſtory of Aleppo, ſays, that it is the cuſtom among the Turkiſh women to black the inſide of their eyelids, not only as an ornament, but as a means of ſtrengthening the ſight. When the eyelids are loſt, a ſymptom which frequently follows a malignant ſmall-pox, the ſight is always conſiderably impaired.

By ſhutting the eyelids partially, we can exclude as much light as we pleaſe, and thus further defend the eyes from too ſtrong a light, which every one's experience proves to be as injurious to them as more groſs matter. Numerous are the melancholy inſtances on record, which confirm this truth: Xenophon relates, that many of his troops were blinded by the ſtrong reflection from the ſnow over which they were obliged to march. Dionyſius, the tyrant of Sicily, among other means which he uſed to gratify his revenge, and ſatiate the cruelty of his temper, was accuſtomed to bring forth his miſerable captives from the deep receſſes of the darkeſt dungeons, into white and well-lighted rooms, that he might blind them by the ſudden tranſition from one extreme to the other. Actuated by principles equally cruel, the Carthaginians cut off the eyelids of Regulus, and then expoſed him to the bright rays of the ſun, by which he was very ſoon blinded.

Theſe facts make it clear that a protuberant eye is not ſo well calculated for viſion, as one that is deep ſunk in the head: neither extreme is indeed deſirable; yet undoubtedly, of the two, that which is deep ſet is preferable, as affording the cleareſt ſight, and being leaſt liable to injuries from external accidents.

Thoſe animals which have hard cruſtaceous eyes, as the lobſter, crab, &c. have no eyelids; whereas moſt brute animals have an additional one, called the *nictitating membrane*, which they draw over their eyes like a curtain, to wipe off whatever incommodes them.

The velocity with which the eyelids move to and fro is ſo great, that it does not in the leaſt impede the ſight. This curious circumſtance may be illuſtrated by the well-known phenomenon of a burning coal appearing like a ring of fire, when whirled round about with rapidity, in the circumference of a circle. Now it is highly probable, that the ſenſation of the coal, in the ſeveral places of the circle, remains on the mind until it returns again to the ſame place. If, therefore, our eyelids take no longer time to paſs and repaſs upon our eyes, than what the coal of fire takes to go round, the impreſſion made by any object on the eye will ſuffer no ſenſible interruption from this motion.

To prevent the eyelids adhering together, they are ſupplied with a row of ſebaceous glandules, which diſcharge a ſoft liniment, that mixes with, and is waſhed off with the tears.

The *lachrymal gland* is placed in the upper and outer part of the orbit. It is deſigned to furniſh at all times water enough to keep the outer ſurface of the eye moiſt, and thus give the cornea a greater degree of pellucidity. In order that this liquor may be rightly diſpoſed of, we frequently cloſe the eyelids without being conſcious of it.

At the inner corner of the eye, between the eyelids, ſtands a caruncle, whoſe office ſeems to be to keep that corner of the eye from being totally cloſed; ſo that any tears, &c. may flow from under the eyelids, when we ſleep, into the *puncta lachrymalia*, which are little holes, one in each eyelid, near the corner, for carrying into the noſe any ſuperfluous tears.

The eye is furniſhed with ſix muſcles, which ſpread their tendons far over the eye; by theſe it can be moved upwards and downwards to either ſide, and in every intermediate direction, and thus view ſurrounding objects without moving the head. To facilitate theſe motions, a great quantity of looſe fat is placed all round the globe of the eye, between it and the orbit. Four of the muſcles are ſtrait, and two oblique; of the two ſtrait muſcles, two are ſituated vertically oppoſite one another, and the other two horizontally. Each of the ſix has a proper name, according to it's ſituation and office. I cannot paſs over the muſcles, without taking notice of a ſtriking inſtance of deſign in the wiſe diſpoſition of the parts. It is ſometimes neceſſary to have an oblique motion of the eye, towards the noſe, and there being no room on that ſide for muſcles, a ſmall bone is placed on the ſide of the noſe, with a hole in it, to ſerve as a pulley, through which the tendon of a muſcle paſſes to a convenient inſertion, and thereby ſuch an oblique motion is given to the eye, as would otherwiſe have been impoſſible.

The eyes are placed in the moſt eminent part of the body, near the brain, the ſeat of ſenſation. From their elevated ſituation, our proſpect is enlarged, and the number of objects taken in at one view, increaſed; we command an ample horizon on earth, and a glorious hemiſphere of the heavens.

Every part of the human frame affords indiſputable proofs of the wiſdom and beneficence of it's Creator, becauſe all are adapted to anſwer in the beſt manner the end for which they were formed. Thus the globular figure of the eye is the moſt commodious we can form any idea of, the beſt adapted for facilitating the various motions of the eye, for containing the humours within, and receiving the images from without.

Many are the advantages that are derived from our having two eyes, ſome that are known, others

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that are unknown; for the correſpondence of the double parts in the human frame, and their relation to the two great faculties of the human mind, has not been ſufficiently attended to by anatomiſts. By having two eyes, the ſight is rendered ſtronger, and the viſion more perfect; for as each eye looks upon the ſame object, a more forcible impreſſion is made, and a livelier conception formed by the mind.

The eyes together view an object in a different ſituation from what either of them apart would do, and enable us to perceive ſmall diſtances accurately. Hence we find, that thoſe who have loſt the ſight of one eye, are apt to make miſtakes in the diſtances of objects, even within arm's length, that are eaſily avoided by thoſe who ſee with both eyes. Such miſtakes are principally ſeen in ſnuffing a candle, threading a needle, or in filling a tea-cup. This aptneſs to misjudge diſtances and ſituations is, however, gradually diminiſhed by time and practice.

When an object is placed at a moderate diſtance, we ſee more of it by means of the two eyes, than we poſſibly could with one; the right eye ſeeing more of the right ſide, and the left eye more of it's correſponding ſide. Thus by both eyes we ſee in ſome meaſure round an object: and it is this which aſſiſts in giving that bold relievo, which we ſee in nature, and which no painting, how exquiſite ſoever, can attain to. The painter muſt be contented with ſhading on a flat ſurface; but the eyes, in obſerving natural objects, perceive not only the ſhading, but a part of the figure that lies behind thoſe very ſhadings. The perception we have of diſtance with one eye, as was juſt now obſerved, is more uncertain, and more liable to deception, than that which we have by both; therefore, if the ſhading and relief be executed in the beſt manner, the picture may have almoſt the ſame appearance to one eye as the objects themſelves would have, but it cannot have the ſame appearance to both. This is not the fault of the artiſt, but an imperfection in the art. To remove theſe defects, the connoiſſeurs in painting look at a picture with one eye through a tube, which excludes the view of all other objects. If the aperture in the tube next the eye be ſmall, we have no means left to judge of the diſtance but the light and colour, which are in the painter's power.*

An object ſeen with both eyes, appears a little brighter, or more luminous, than it does when ſeen with one alone, as will be evident by looking alternately with both eyes and with one only: and the difference of brightneſs will be ſtill more manifeſt, if at the ſame time that a part of a flat object, of an uniform colour, is ſeen with both eyes, the light from the adjacent part is excluded from one of them; which may be done, by applying a book to one ſide of the head, ſo that it may reach a little forwarder than the face. But although the difference of brightneſs, in the two caſes, is very perceptible, yet it is not very conſiderable, nor is it eaſy to determine it accurately. Dr. Jurin, by a variety of experiments, concluded, that an object ſeen with both eyes, appeared only one thirteenth part brighter, than when ſeen with one alone.

Our eyes have an uniform or parallel motion, by which, when one is turned to the right or left, upwards or downwards, or ſtrait forwards, the other always goes along with it in the ſame direction. When both eyes are open, we find them always turned the ſame way, as if both were acted upon by the ſame motive force. This phenomenon is the more ſingular, as the muſcles which move the two eyes, and the nerves which ſerve the muſcles, are entirely diſtinct and unconnected.

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* Reid's Inquiry into the Human Mind.

To account for and explain the cauſe of this motion, has puzzled the philoſopher, and embarraſſed the anatomiſt: that it originates from the grand moving principle, or generating cauſe within us, the mind, there can be little doubt; but how the mind operates, to produce this effect, we are altogether ignorant. Some effectual purpoſes are no doubt anſwered by this motion, for nothing is created in vain. One is ſuppoſed to be that of ſeeing objects ſingle that are viewed with both eyes; for there are two pictures formed of every object, one in each eye. Hence, if any of the muſcles of one eye, either from ſpaſm, paralyſis, or any other cauſe, is reſtrained from following the motion of the other, every object will be ſeen double. The ſame effect is produced, if, while we are looking at any object, we alter the direction of one of our eyes, by preſſing it aſide by the finger; an experiment frequently made by children, who are generally delighted with any uncommon appearance.

Whatever may be the cauſe, the fact is certain, that the object is not multiplied as well as the organ, and appears but one, though ſeen with two eyes: another inſtance of the ſkill of the contriver of this noble organ, and the exquiſite art he employed in the formation of it.

Having conſidered the principal external parts of the eye, and ſhewn that they are framed to protect this delicate organ, with a care ſtrictly proportioned to it's curious texture, and extenſive uſefulneſs, that it is fortified with ſtrong bones, lodged in a deep receptacle, and guarded with a moveable cover; we now proceed to treat of the internal parts, or thoſe which conſtitute the globe of the eye.

OF THE GLOBE OF THE EYE.

"If the conſtruction of the univerſe were not ſo evident a proof of the exiſtence of a ſupremely wiſe and benevolent Creator, as to render particular arguments unneceſſary, the ſtructure of the eye might be offered as one, by no means the leaſt; this inſtance, among numberleſs others, demonſtrating that the beſt performances of art are infinitely ſhort of thoſe which are continually produced by the DIVINE MECHANIC.

The globe of the eye, or the organ of ſight, may be defined in general as a kind of caſe conſiſting of ſeveral coats, containing three pellucid humours, which are ſo adjuſted, that the rays proceeding from luminous objects, and admitted at a hole in the fore part of the eye, are brought to a focus on the back part of it, where they fall upon a ſoft pulpy ſubſtance, from whence the mind receives it's intelligence of viſible objects.

It is not to be expected, that any account given of the eye can be altogether accurate; for as it is impoſſible to examine all the parts of the eye whilſt in a natural and living ſtate, ſo is it alſo nearly impoſſible, when it is taken out of it's ſocket, to preſerve the figure of the parts entire; a circumſtance which accounts for the diſagreement we find among anatomiſts.

OF THE COATS OF THE EYE.

The eye is compoſed externally of three coats or teguments, one covering the other, and forming a ball perfectly globular, except at the fore part, which is a little more protuberant than the reſt; within this ball are three different ſubſtances, called humours.

The firſt, or outer coat, is called the *ſclerotica*;

the ſecond, or middle one, is called the *choroides*; the interior one is named the *retina*.

Sclerotica. Cornea. The exterior membrane, which incloſes and covers the whole eye, is called ſclerotica and cornea: it is, however, ſtrictly ſpeaking, but one and the ſame membrane, with different names appropriated to different parts; the hinder and opake part being more generally denominated the ſclerotica, the fore and tranſparent part the cornea.

The *ſclerotica* is hard, elaſtic, of a white colour, reſembling a kind of parchment; the hinder part is very thick and opake, but it grows gradually thinner as it advances towards the part where the white of the eye terminates. The fore part is thinner, and tranſparent; it is alſo more protuberant and convex than the reſt of the eye, appearing like a ſegment of a ſmall ſphere applied to a larger, and is called *cornea* from it's tranſparency. The cornea is thick, ſtrong, and inſenſible; it's tranſparency is neceſſary for the free admiſſion of the light. This membrane is compoſed of ſeveral plates, laid one over the other, repleniſhed with a clear water, and pellucid veſſels; theſe plates are more evidently diſtinct in the fore than the hinder part. The ſclerotica is embraced on it's outſide by ſix muſcles, by which the eye may be moved in any direction.

Choroides. Uvea. Iris. Under the ſclerotica is a membrane, known by the name of the *choroides*; it is a ſoft and tender coat compoſed of innumerable veſſels; it is concentric to the ſclerotica, and adheres cloſely to it by a cellular ſubſtance, and many veſſels. This membrane is outwardly of a brown colour, but inwardly of a more ruſſet brown, almoſt black. Like the ſclerotica, it is diſtinguiſhed by two different names; the fore part being called the *uvea*, while the hinder part retains the name of the *choroides*.

The fore part commences at the place where the cornea begins: it here attaches itſelf more ſtrongly to the ſclerotica by a cellular ſubſtance, forming a kind of white narrow circular rim: the choroides ſeparates at this place from the ſclerotica, changes it's direction, turning, or rather folding, directly inwards, towards the axis of the eye, cutting the eye as it were tranſverſely: in the middle of this part is a round hole, called the pupil, or ſight of the eye: the pupil is not exactly in the middle of the iris, that is to ſay, the centers of the pupil and iris do not coincide, the former being a little nearer the noſe than the latter.

This part, when it has changed it's direction, is no longer called the choroides; but the anterior ſurface, which is of different colours, in different ſubjects, is called the *iris*; the poſterior ſurface is called the *uvea*, from the black colour with which it is painted. The iris has a ſmooth velvet-like appearance, and ſeems to conſiſt of ſmall filaments regularly diſpoſed, and directed towards the center of the pupil.

The eye is denominated blue, black, &c. according to the colour of the iris. The more general colours are the hazel and the blue, and very often both theſe colours are found in the ſame eye. It has been obſerved, that in general thoſe, whoſe hair and complexion are light-coloured, have the iris blue or grey; and on the contrary, thoſe whoſe hair and complexion are dark, have the iris of a deep brown: whether this occaſions any difference in the ſenſe of viſion, is not diſcoverable. Thoſe eyes which are called black, when narrowly inſpected, are only of a dark hazel colour, appearing black, becauſe they are contraſted with the white of the eye. " The black and the blue are the moſt beautiful colours, and give moſt fire and vivacity of expreſſion to the eye. In black eyes there is more force and impetuoſity; but the blue excel in ſweetneſs and delicacy."

The pupil of the eye has no determinate ſize, being greater or ſmaller, according to the quantity of light that falls upon the eye. When the light is ſtrong, or the viſual object too luminous, we contract the pupil, in order to intercept a part of the light, which would otherwiſe hurt or dazzle our eyes; but when the light is weak, we enlarge the pupil, that a greater quantity may enter the eye, and thus make a ſtronger impreſſion upon it. This aperture dilates alſo for viewing diſtant objects, and becomes narrower for ſuch as are near. The contraction of the pupil is a ſtate of violence, effected by an exertion of the will: the dilatation is a remiſſion of power, or rather an intermiſſion of volition. * The latitude of contraction and dilatation of the pupil is very conſiderable; and it is very admirable, that while the pupil changes it's magnitude it preſerves it's figure.

Anatomiſts are not agreed, whether the iris be compoſed of two ſets of fibres, the orbicular and radial, or of either. Haller ſays, he could never diſcover the orbicular fibres, even with a microſcope; the radial ſeem viſible to the naked eye, and are ſufficient to anſwer all the purpoſes required in the motion of the iris: when the pupil is contracted the radial fibres are ſtrait, when it is dilated they are drawn into ſerpentine folds.

In children this aperture is more dilated than in grown perſons. In elderly people it is ſtill ſmaller than in adults, and has but little motion; hence

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* Anatomiſts obſerve, that in animals of prey, both beaſts and birds, the pupil is round as in man, which fits them to ſee every way; but in large animals which feed on graſs, the pupil is oblong horizontally, for taking in a large circular ſpace of ground: the pupil in animals of the cat kind, which climb trees, and want to look upwards and downwards, is oblong vertically.

hence it is, that thoſe who begin to want ſpectacles, are obliged to hold the candle between the eye and the paper they read, that the ſtrong light of the candle may force their rigid pupils into ſuch a ſtate of contraction, as will enable them to ſee diſtinctly. Thoſe who are ſhort-ſighted, have the pupils of their eyes, in general, very large; whereas in thoſe whoſe eyes are perfect, or long-ſighted, they are ſmaller.

The whole of the choroides is opake, by which means no light is allowed to enter into the eye, but what paſſes through the pupil. To render this opacity more perfect, and the chamber of the eye ſtill darker, the poſterior ſurface of this membrane is covered all over with a black mucus, called the pigmentum nigrum. This pigment is thinneſt upon the concave ſide of the choroides, near the retina, and on the fore ſide of the iris; but is thickeſt on the exterior ſide of the choroides, and the inner ſide of the uvea.

The circular edge of the choroides, at that part where it folds inwards to form the uvea, ſeems to be of a different ſubſtance from the reſt of the membrane, being much harder, more denſe, and of a white colour; it has been called by ſome writers the ciliary circle, becauſe the ligamentum ciliare (of which we ſhall ſoon ſpeak) ariſes from it.

Retina. The third and laſt membrane of the eye is called the retina, becauſe it is *ſpread* like *a net* over the bottom of the eye; others derive the name from the reſemblance of the net which the gladiators called retiarii, employed to entangle their antagoniſts. It is the thinneſt and leaſt ſolid of the three coats, a fine expanſion of the medullary part of the optic nerve. The convex ſide of it lines the choroides, the concave ſide covers the ſurſace of the vitreous humour, terminating where the choroides folds inwards. It is an eſſential organ of viſion; on it the images of objects are repreſented, and their picture formed. This membrane appears to be black in infants, not ſo black at the age of twenty, of a greyiſh colour about the thirtieth year, and in very old age almoſt white. The retina, however, is always tranſparent and colourleſs: any apparent changes, therefore, of it's colour muſt depend upon alterations of the *pigmentum*, which is ſeen through it.

Optic Nerve. Behind all the coats is ſituated the optic nerve, which paſſes out of the ſcull, through a ſmall hole in the bottom of the orbit which contains the eye. It enters the orbit a little inflected, of a figure ſomewhat round, but compreſſed, and is inſerted into the globe of the eye, not in the middle, but a little higher and nearer to the noſe; an artery runs through the optic nerve, goes ſtrait through the vitreous humour, and ſpreads itſelf on the membrane that covers the backſide of the cryſtalline.

Monſ. Mariotte has demonſtrated, that our eyes are inſenſible at the place where the optic nerve enters; if, therefore, this nerve had been ſituated in the axis of the eye itſelf, then the middle part of every object would have been inviſible, and where all things contribute to make us ſee beſt, we ſhould not have ſeen at all; but it is wiſely placed by the divine artiſt for this and other advantageous purpoſes, not in the middle, but, as we have already obſerved, a little higher and nearer to the noſe.

OF THE HUMOURS OF THE EYE.

The coats of the eye, which inveſt and ſupport each other, after the manner of an onion, or other bulbous root, include it's humours, by which name are underſtood three ſubſtances, the one a ſolid, the ſecond a ſoft body, and the third truly a liquor. Theſe ſubſtances are of ſuch forms and tranſparency, as not only to tranſmit readily the rays of light, but alſo to give them the poſition beſt adapted for the purpoſes of viſion. They are clear like water, and do not tinge the object with any particular colour.

Aqueous Humour. The moſt fluid of the three humours is called the aqueous one, filling the great interſtice between the cornea and the pupil, and alſo the ſmall ſpace extending from the uvea to the cryſtalline lens; it is thin and clear like water, though ſomewhat more ſpirituous and viſcous; it's quantity is ſo conſiderable, that it ſwells out the fore part of the eye into a protuberance very favourable to viſion. The uvea ſwims in this fluid. It covers the forepart of the cryſtalline; that part of this humour, which lies before the uvea, communicates with that which is behind, by the hole which forms the pupil of the eye. It is included in a membrane, ſo tender, that it cannot be made viſible, nor preſerved, without the moſt concentrated lixivial fluid.

It has not been clearly aſcertained whence this humour is derived; but it's ſource muſt be plentiful; for if the coat containing it be ſo wounded that all the humour runs out, and the eye be kept cloſed for a ſeaſon, the wound will heal, and the fluid be recruited.

The colour and conſiſtence of this humour alters with age; it becomes thicker, cloudy, and leſs tranſparent, as we advance in years, which is one reaſon, among others, why many elderly people do not reap all that benefit from ſpectacles which they might naturally expect.

Cryſtalline. The ſecond humour of the eye is the *cryſtalline*, which is as tranſparent as the pureſt cryſtal; and though leſs in quantity than the aqueous humour, yet it is of equal weight, being of a more denſe and ſolid nature; in conſiſtency it is ſomewhat like a hard jelly, growing ſofter from the middle outwards. It's form is that of a double convex lens, of unequal convexities, the moſt convex part being received into an equal concavity in the vitreous humour.

The cryſtalline is contained in a kind of caſe, or capſule, the fore part of which is very thick and elaſtic, the hinder part is thinner and ſofter. This capſule is ſuſpended in it's place by a muſcle called *ligamentum ciliare*, which, together with the cryſtalline, divides the globe of the eye into two unequal portions; the firſt and ſmaller one contains the aqueous humour, the hinder and larger part the vitreous humour. The cryſtalline has no viſible communication with it's capſule, for as ſoon as this is opened the humour within ſlips clean out.

The cryſtalline is placed ſo, that it's axis correſponds with that of the pupil, and conſequently it is not exactly in a vertical plane dividing the eye into two equal parts, but ſomewhat nearer the noſe. It is formed of concentric plates or ſcales, ſucceeding each other, and theſe ſcales are formed of fibres elegantly figured, and wound up in a ſtupendous manner; theſe are connected by cellular fibres, ſo as to form a tender cellular texture. Between theſe ſcales is a pellucid liquor, which in old age becomes of a yellow colour. The innermoſt ſcales lie cloſer together, and form at laſt a ſort of nucleus, harder than the reſt of the lens. The cryſtalline has no viſible communication with it's capſule, ſo that when this is opened, it readily ſlips out: ſome ſay, that a ſmall quantity of water is effuſed round it. Leeuwenhoeck has computed that there are near two thouſand laminæ, or ſcales, in one cryſtalline, and that each of theſe is made up of a ſingle fibre, or fine thread, running this way and that, in ſeveral courſes, and meeting in as many centers, and yet not interfering with, or croſſing each other.

The yellow colour, wherewith the cryſtalline is more and more tinged as we advance in years, muſt make all objects appear more and more tinged with that colour: nor does our being inſenſible of any change in the colour of objects, prove to us that their colour continues the ſame; for in order that we ſhould be ſenſible of this change, the tincture muſt not only be conſiderable, but it muſt happen on a ſudden, as will be more fully explained hereafter. In the cataract it is opake; the ſeat of this diſorder is in the cryſtalline lens.

Vitreous Humour. The vitreous is the third humour of the eye; it receives it's name from it's appearance, which is like that of melted glaſs. It is neither ſo hard as the cryſtalline, nor ſo liquid as the aqueous humour; it fills the greateſt part of the eye, extending from the inſertion of the optic nerve to the cryſtalline humour. It ſupports the retina, and keeps it at a proper diſtance for receiving and forming diſtinct images of objects.

The vitreous humour is contained in a very thin pellucid membrane, and concave at it's fore part, to receive the cryſtalline; at this place it's membrane divides into two, the one covering the cavity in which the cryſtalline lies, the other paſſing above, and covering the fore part of the cryſtalline, thus forming a kind of ſheath for the cryſtalline. The fabric of the vitreous humour is cellular, the ſubſtance of it being divided by a very fine tranſparent membrane into cellules, or little membranous compartments, containing a very tranſparent liquor.

Ligamentum Ciliare. There is ſtill one part to be deſcribed, which, though very delicate and ſmall, is of great importance; it is called the ligamentum ciliare, becauſe it is compoſed of ſmall filaments, or fibres, not unlike the cilia, or eyelaſhes; theſe fibres ariſe from the inſide of the choroides, all round the circular edge, where it joins the uvea; from whence they run upon the fore part of the vitreous humour, at that place where it divides to cover the cryſtalline; thoſe fibres are at ſome diſtance from one another, but the interſtices are filled up with a dark-coloured mucus, giving it the appearance of a black membrane.

OF THE FIGURE REPRESENTING THE EYE.

Figure 1, repreſents a ſection of the eye through the middle, by an horizontal plane paſſing through both eyes; the diameter of the figure is about twice the diameter of the human eye.

The outermoſt coat, which is called *ſclerotica*, is repreſented by the ſpace between the two exterior circles B F B; the more globular part, adjoining to the ſclerotica at the points B B, repreſented by the ſpace between the two circles at B A B, is the *cornea.*

The next coat under the ſclerotica is a membrane of leſs firmneſs, repreſented by the two innermoſt circles of B F B, and called the *choroides.*

Adjoining to the choroides, at B B, is a flat membrane, called the uvea. a a is the pupil, being a ſmall hole in the uvea, a little nearer the noſe than the middle.

V the *optic nerve;* the fibres of this nerve, after their entrance into the eye, ſpread themſelves over the choroides, forming a thin membrane, called the retina, and is repreſented in the figure by the thick ſhade contiguous to the circle B F B.

E E is the *cryſtalline* humour; it is ſuſpended by a muſcle B b b B, called the *ligamentum ciliare.* This muſcle ariſes behind the uvea at B B; where the ſclerotica and cornea join together at b b, it enters the capſula, and thence ſpreads over a great part of it's anterior ſurface.

The *aqueous* humour occupies the ſpace B A B b C b.

The larger ſpace B b D b B F contains the *vitreous* humour.

The foregoing deſcription, I preſume, will be found ſufficient to give a general idea of the conſtruction of this wonderful organ: for a fuller account I muſt refer you to the writers on anatomy. Enough has been exhibited to ſhew with what art and wiſdom the eye has been conſtructed. "And he muſt be very ignorant of it's ſtructure, or have a ſtrange caſt of underſtanding, who can ſeriouſly doubt, whether or not the rays of light and the eye were made for one another, with conſummate wiſdom, and perfect ſkill in optics."

"If we ſhould ſuppoſe an order of beings endued with every human faculty but that of ſight, how incredible would it appear to ſuch beings, accuſtomed only to the ſlow information of touch, that, by the addition of an organ, conſiſting of a ball and ſocket of an inch diameter, they might be enabled, in an inſtant of time, without changing their place, to perceive the diſpoſition of a whole army, the order of a battle, the figure of a magnificent palace, or all the variety of a beautiful landſcape? If a man were, by feeling, to find out the figure of the Peak of Teneriffe, or even of St. Peter's church at Rome, it would be the work of a life-time.

"It would appear ſtill more incredible to ſuch beings as we have ſuppoſed, if they were informed of the diſcoveries which may be made by this little organ, in things far beyond the reach of any other ſenſe. That, by means of it, we can find our way on the pathleſs ocean, traverſe the globe of the earth, determine it's ſize and figure, meaſure the planetary orbs, and make diſcoveries in the ſphere of the fixed ſtars.

"Would it not appear ſtill more aſtoniſhing to theſe beings, if they ſhould be further informed, that by means of this organ we can perceive the tempers and diſpoſitions, the affections and paſſions, of our fellow-creatures, even when they want moſt to conceal them? that by this organ we can often perceive what is ſtrait and crooked, in the mind as well as the body? that it participates of every mental emotion, the ſofteſt and moſt tender, as well as the moſt violent and tumultuous? that it exhibits theſe emotions with force, and infuſes into the ſoul of the ſpectator the fire and the agitation of that mind in which they originate? To many myſterious things muſt a blind man give credit, if he will believe the relations of thoſe that ſee! his faith muſt exceed that which the poor ſceptic derides as impoſſible, or condemns as abſurd.

"It is not, therefore, without reaſon, that the faculty of ſeeing is looked upon as more noble than the other ſenſes, as having ſomething in it ſuperior to ſenſation, as the ſenſe of the underſtanding, the language of intelligence. The evidence of reaſon is called *ſeeing*, not feeling, ſmelling, taſting; nay, we expreſs the manner of the divine knowledge by *ſeeing*, as that kind of knowledge which is the moſt perfect in ourſelves."*

OF

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* Reid's Inquiry into the Human Mind.

OF VISION.

The repreſentation of objects upon a ſheet of paper, by means of a lens placed at a hole in a window-ſhutter, is exceedingly ſimilar to what happens to our eyes when we view objects. For viſion, ſo far as our eyes are concerned, conſiſts in nothing but ſuch a refraction of the rays of light by the tranſparent ſkins and humours of the eye as will form a diſtinct picture of the object on the retina. For the ſtructure of the eye plainly indicates, that in order to attain diſtinct viſion, it is neceſſary that a certain quantity of rays from every viſible point of an object ſhould be united at the bottom of the eye, and that the points of union of the rays of the different pencils ſhould be as diſtinct and ſeparate as poſſible.

The eye is admirably contrived for effecting theſe purpoſes: all the rays coming from any viſible point of an object, that can enter the pupil, are united cloſely together upon the retina, and thereby make a much more powerful and ſtronger impreſſion than a ſingle ray alone could do; to anſwer this purpoſe, the retina is placed at a proper diſtance behind the refracting ſurfaces, and each pencil of rays is refracted orderly into diſtinct focuſes, that the whole object may be diſtinctly ſeen at the ſame inſtant.

Theſe effects are owing to the refraction of the rays of light; for if theſe rays were not ſo refracted, very few of them would ſtrike upon the leaſt ſenſible point of the viſionary nerve, and the rays from different objects, or from different parts of the ſame objects, would ſtrike at the ſame place at once, and thus create an indiſtinctneſs equal to blindneſs.

When the light is weak or ſtrong, the pupil is accordingly enlarged or contracted, for the admiſſion of more or fewer rays, that the impreſſions on the retina may be rendered ſuitable to the reſpective caſes.

As the cryſtalline humour is denſeſt in the middle, it is highly probable that it is not equally refractive. This difference in denſity of the conſtituent parts of the cryſtalline is admirably contrived for correcting the aberration from it's figure, as well as that of the cornea. The more remote rays of each pencil, by paſſing through a medium gradually diminiſhing in denſity from the middle towards the extremes, have their focuſes gradually lengthened, which correct the aberrations of the figure, that ſo they may unite nearer together. The concave figure of the retina is ſomewhat ſerviceable for the ſame purpoſe.

It is by no means eaſy to determine with accuracy the meaſure of refraction of the different humours of the eye; from ſuch experiments as could be made, it has been found that the refractive powers of the aqueous and vitreous humours are much the ſame with common water, and that of the cryſtalline a little greater.

The cornea and aqueous humour being ſuppoſed to have the ſame refractive powers, all three may be conſidered as one denſe medium, whoſe refractive ſurface is the cornea; and the cryſtalline humour may be conſidered as a convex lens, placed in a given poſition, within the ſaid medium. Whence the humours of the eye all together make a kind of compound lens, whoſe effect in refracting rays, having a given focus of incidence, is eaſily found by the laws of optics.

I have conſtructed three models to explain the action of the rays of light upon the eye. Theſe models are repreſented at *fig.* 8 and 9, *pl.* 3; *fig.* 10, *pl.* 4. The rays of light are here formed of ſilk ſtrings of different colours; the globe of the eye is repreſented by a glaſs ball. *Fig.* 8, *pl.* 3, is the natural ſtate of the eye. *Fig.* 9, *pl.* 3, repreſents the rays falling ſhort of the retina for a ſhort-ſighted eye. *Fig.* 10, *pl.* 4, exhibits the action of the rays in a long-ſighted eye. Let P Q R, *fig.* 8, *pl.* 3, be an object; then the pencils of light B P B, B Q B, B R B, from the points P Q R, are firſt refracted by the cornea, ſo as to belong to focuſes behind the eye; then by the anterior ſurface of the cryſtalline humour, they are again refracted towards focuſes nearer to the eye than before; and laſtly, in going out of the cryſtalline into the vitreous humour, they are again refracted, ſo as to unite in the points p q r. In like manner, the pencils of rays coming to the cornea from every phyſical point of the object P Q R, are, by the different refracting ſurfaces of the eye, brought orderly to unite upon the retina, and there form, as it were, an image p q r of the object, but in an inverted poſition; the upper part of the object being painted upon the lower part of the retina, the right ſide of the object upon the left of the retina, and ſo of other parts. Thus the cavity of the eye is a kind of *camera obſcura*, the cornea and cryſtalline making a ſort of compound lens, whoſe aperture is limited by the breadth a a of the pupil. And that the parts of the eye are adapted to produce ſuch an image, may be proved by experiment: for if the tunica ſclerotica be taken away from the back of an eye newly taken out of the head of any animal, and this eye be placed in a hole made in the window-ſhutter of a dark room, ſo that the bottom of the eye be towards you, a beautiful, but inverted, picture of external objects will be exhibited, painted in the moſt lively colours.

If the humours of the eye, by age, or any other cauſe, ſhrink and decay, the cornea and cryſtalline grow flatter than before; and the rays not being ſufficiently bent, arrive at the retina before they are united in their focus, and meet in ſome place behind it, ſee *fig.* 13, *pl.* 4, and therefore form an imperfect picture at the bottom of the eye, and exhibit the object in a confuſed and indiſtinct manner. This defect, of which we ſhall treat more particularly hereafter, is remedied by ſpectacles with convex glaſſes, which, by increaſing the refraction of the rays of light, cauſe them to converge more, and thus convene diſtinctly at the bottom of the eye.

On the other hand, if the cornea and cryſtalline be too convex, the rays unite before their arrival at the retina, ſee *fig.* 9, *pl.* 3; and the image thereon is of courſe indiſtinct. This defect, like the preceding one, may be remedied by the uſe of glaſſes, though of a contrary figure; for here they muſt be concave, inſtead of convex: a lens, of a proper concavity, placed before the eye, will make the rays diverge ſo much more than they do in their natural ſtate, as will cauſe them to meet at the retina.

OF THE ARTIFICIAL EYE.

If the eye of an animal be taken out, and the ſkin and fat be carefully ſtripped off from the back part of it, till only the thin membrane, which is called the retina, remains to terminate it behind, and any object be placed before the front of the eye, the picture of that object will be ſeen figured as with a pencil on the retina. There are thouſands of experiments which prove that this is the mechanical effect of viſion; but none of them which render it ſo evident as this with the eye of an animal: an eye of an ox newly killed, ſhews it happily, and with very little trouble.

The optical effects of viſion may be very pleaſingly and ſatisfactorily illuſtrated by the inſtrument which is called an *artificial eye*, and which has been lately conſiderably improved by Mr. Smith.

The artificial eye is ſo conſtructed as not only to ſhew the optical effects of viſion, but to give alſo an accurate idea of it's conformation. It is one of the moſt perfect and ſatisfactory inſtruments in a philoſophical apparatus.

The part repreſenting the globe of the eye, and containing the humours, is fixed in a ſocket where it may be moved in any direction. This ſocket is fixed to a ſcreen to ſhade the eye, that the picture formed on the back part may be more diſtinct: the hole in the front of the ſcreen is ſhaped and coloured ſo as to exhibit nearly the form of our eye.

Take the eye in your hand, and turn it towards any bright object, at a moderate diſtance, and you will ſee a lively, beautiful, diſtinct, but inverted picture of the object before it, on the rough part of the glaſs repreſenting the retina.

Unſcrew the cover that confines the ball of the eye, and take it out that we may diſſect it. The outermoſt coat repreſents the *ſclerotica*, the more protuberant part is the *cornea*.

This being removed, you find a plano-convex lens, repreſenting the *firſt* chamber of the *aqueous* humour; under this is a flat piece of tortoiſeſhell, to repreſent the *iris*, with a hole in the middle for the *pupil*; this being removed, you find a plano-concave lens, forming the *ſecond* chamber of the aqueous humour. Now take off the ſecond coat, or the choroides, and you will find a ſmall lens, whoſe ſides are of unequal convexities, to repreſent the *cryſtalline* humour; underneath this is a large glaſs of the ſhape EDEV, *fig*. 10, *pl*. 3, occupying the reſt

of

of the globular ſpace, and anſwering to the vitreous humour.

To repreſent the nature of viſion in a long-ſighted eye, I ſubſtitute a plano-convex lens for the firſt chamber of the aqueous humour, whoſe convexity is leſs than that we uſed before. Turn the eye, in this ſtate, towards a bright object, and you find the image thereof is very imperfect on the retina; but on applying a proper ſpectacle glaſs before the eye, you obtain a perfect image.

By ſubſtituting a more convex lens for the firſt chamber of the aqueous humour, we have a ſhort-ſighted eye, and an imperfect picture on the retina: by placing a proper concave lens before the eye, the rays are rendered leſs convergent, and made to unite at the retina, and there form a diſtinct image of the objects as before.

OF THE INVERTED POSITION OF THE IMAGE.

If viſion be owing to the picture on the retina, it may be aſked, why the object appears in it's natural *upright poſition?* how, when nature draws the picture the wrong way, her errors are ſo readily corrected?

If it were as eaſy a taſk to give a ſatisfactory explanation of this abſtruſe queſtion, as it is to ſtart objections to every ſyſtem hitherto ſuggeſted, to account for the operations of the mind on the body, and the body on the mind, it would have been explained long ago.*

The difficulty would be ſtill greater, if it was the picture we ſaw, and not the object; but the picture *is not ſeen at all*, the eye can ſee no part of itſelf; the picture is the inſtrument, by means of which the object is perceived; but it is not perceived itſelf; the inſtrument neither perceives, compares, nor judges; theſe are powers peculiar to that pſycological unity which we call the *mind.*

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* See, on this ſubject, Reid on the Mind, Porterfield on the Eye, Hartley on Man, Bonnet's Eſſai Analytique ſur l'Ame, Berkeley on Viſion, &c. &c.

It is abſolutely neceſſary, in conſidering this ſubject, to diſtinguiſh between the organ of perception, and the *being* that perceives. A man cannot ſee the ſatellites of Jupiter, unleſs aſſiſted by a teleſcope: does he therefore conclude from this, that it is the teleſcope that ſees thoſe ſatellites? By no means; the concluſion would be abſurd: nor would it be leſs abſurd to conclude, that it is the eye that ſees: the eye is a natural organ of ſight, but the natural organ ſees as little as the artificial.

Our ſenſes are inſtruments, ſo framed by the Author of our being, that they correſpond with, or have a determined relation to, thoſe qualities in objects which they are to manifeſt to us. It is thus with the eye; it is an inſtrument moſt admirably contrived for manifeſting viſible objects to the mind; for this purpoſe, it refracts the rays of light, and forms a picture upon the retina; but it neither ſees the object, nor the picture. The eye will refract the rays of light, and form the picture, after it is taken out of the head, but no viſion enſues. Even, when it is in it's proper place, and perfectly ſound, an obſtruction in the optic nerve takes away viſion, though the eye has performed all it's functions.

We know, indeed, how the eye forms a picture of viſible objects on the retina; but how this picture makes us ſee objects, we know not: and if experiment had not informed us that ſuch a picture was neceſſary, we ſhould have been entirely ignorant of it. The ſeat of ſenſation, wherever it is placed, does not appear to be paſſive in receiving images; the images are the occaſion of it's re-action, and directing a ray from itſelf towards every object it perceives; and this action and re-action are reciprocal. Hence we often ſee objects when the eye is turned from them, and often do not ſee the object on which the eye is turned, if the attention be otherwiſe engaged.

The pictures upon the retina are, however, a mean of viſion; for ſuch as the picture is, or ſuch as the action of the rays of light is on the retina, ſuch is the appearance of the object in colour and figure, diſtinctneſs or indiſtinctneſs, brightneſs or faintneſs; but as we are totally ignorant of the mechaniſm of the mind, or of the organization of the mental eye, we cannot ſay how this effect operates, and can only conclude, that the natural eye is an inſtrument of viſion.

It appears very clear from Dr. Darwin's experiments, that the retina is often in an active ſtate, and that upon the activity of this organ many of the phenomena of viſion depend; an impreſſion on the retina being firſt made by an active power, which produces a conformable change and reaction, that paſſes directly to the ſenſorium, occaſioning, though in an unknown manner, the perception of objects.

On a ſubject, therefore, confeſſedly ſo obſcure, and which is perhaps beyond the limits of human conception in it's preſent ſtate, every explanation muſt be imperfect, every illuſtration inadequate. Among the various attempts of human ſagacity, to ſhew why an *inverted image* is the mean of exhibiting objects to the mind in an upright poſition, the following is perhaps one of the leaſt imperfect,

Every point of an object is ſeen in the direction of a right line, paſſing from the picture of that point on the retina, through the center of the eye, to the object point; and, therefore, ſuch points indicate to the mind the exiſtence of the object point, and it's true ſituation; and of courſe, that the object,

ject, whoſe picture is loweſt on the retina, muſt be ſeen in the higheſt direction from the eye; and that object, whoſe picture is on the right of the retina, muſt be ſeen on the left: ſo that by a natural law of our conſtitution, we ſee objects erect by inverted images, and if the pictures had been erect on the retina, we ſhould have ſeen the object inverted.*

But ſuppoſing the preceding illuſtration to be the true one, and quite ſatisfactory, many difficulties ſtill remain, to perplex the philoſopher, and embarraſs the anatomiſt. There are parts of the eye which aſſiſt in perfecting the organ of viſion, whoſe nature and functions are among the deſiderata of ſcience. We are ignorant of the office of the optic nerve, or in what manner it performs that office. That it has ſome part in the faculty of ſeeing, is evident; becauſe in an amauroſis, which is ſaid to be a diſorder of the optic nerve, the pictures on the retina are clear and diſtinct, and yet there is no viſion.

We know ſtill leſs of the uſe and functions of the choroid membrane; it is neceſſary, however, to viſion; for it is well known, that a picture upon that part of the retina where it is not covered with the choroid, namely, at the entrance of the optic nerve, produces no more viſion than a picture upon the hand.† There are, therefore, other material organs, whoſe operations are neceſſary to ſeeing, even after the pictures upon the retina are formed; whenever we become acquainted with the uſe of theſe parts, more links of the chain will be brought into our view, and we ſhall better comprehend this wonderful inſtrument.

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* Reid on the Human Mind.

† This is not concluſive, for where there is no choroid, there is no retina, the optic nerve being not yet expanded into that membrane. If the choroid was taken away from behind the retina, there is reaſon to believe that viſion would ſtill take place.

Having had occaſion to mention that there is no viſion produced by that part of the retina which is not covered by the choroid membrane, it will be proper to illuſtrate this circumſtance more fully, and ſhew in what manner this fact has been aſcertained, the diſcovery of which occaſioned a long controverſy concerning the proper ſeat of viſion.

Experiment. Fix three black patches, A, B, C, upon a white wall, at the height of the eye, A being to the left, and C to the right: place yourſelf facing theſe patches, ſhut the right eye, and direct the left towards the patch C, you will then ſee both A and C, but the middle patch B will diſappear. Or if the left eye be ſhut, and the right directed towards A, you will ſtill ſee both A and C, but B will diſappear. If the eye be directed towards B, both B and A will be ſeen, and not C; for which ever of the patches is directly oppoſite to the optic nerve vaniſhes. This experiment is rather difficult at firſt, but becomes eaſy by a little practice. In our uſual intercourſe with common objects, we are not ſenſible of this defect, becauſe we turn the viſual parts of the eye with ſo much rapidity upon the inviſible part of the object, that the loſs, without peculiar attention, is imperceptible; this loſs, however, in one eye, is remedied by the uſe of both, as the part of the object that is not ſeen by one, will be diſtinctly perceived by the other. This defect of ſight, though common to every human eye, was never known, until it was diſcovered by the ſagacity of Monſ. Mariotte in the laſt century.

Of the Extent or Limits of Vision.

Having conſidered the general principles of viſion, I ſhall now proceed to conſider further the nature, properties, and extent of power of the eyes. As in a dark chamber, a very ſlender beam of light is viſible; ſo in all caſes when the ſurrounding medium is very dark, objects are ſeen by ſmall quantities of light. Hence, when the medium round the eye is dark, a ſmall quantity of light will ſuffice for viſion, the eye being, by the excluſion of the adventitious light, rendered ſenſible to the moſt delicate impreſſions.

The extent, therefore, of our ſight is increaſed or diminiſhed, in proportion to the quantity of light that ſurrounds us, ſuppoſing the illumination of the object to remain the ſame. Hence it has been calculated, that if the ſame object, which during the day we ſee at the diſtance of 3436 times it's diameter, were equally illuminated during the night, it would be viſible at 100 times greater diſtance.

Thus in a dark night the feeble light of a candle may be ſeen at a great diſtance; and the fixed ſtars, though they have no ſenſible diameter, are viſible, and the darker the night, the more of them are ſeen. A certain quantity of light is, however, neceſſary, even in this caſe, for viſion; for the impreſſions of light from the ſatellites of Jupiter and Saturn, are too feeble to be perceived without the aſſiſtance of a teleſcope.

At the approach of day, and as the twilight increaſes, the eye begins to be enlightened by the reflection of the atmoſphere, the ſtars grow fainter, and in proportion as the light increaſes, gradually diſappear, firſt thoſe of the leaſt, and at laſt thoſe of the largeſt magnitude. As the day advances, the moon herſelf loſes of her luſtre, till at length her light is overpowered, and ſhe is no longer ſeen. In the ſame manner, ſmall particles are ſeen floating in a beam of light let into a darkened room; but as ſoon as the room is enlightened, thoſe particles diſappear.

One of the reaſons why we are often unable to diſtinguiſh diſtant objects, is the profuſion of rays reflected from intermediate objects, which, by their brilliancy, prevent us from perceiving the fainter rays that proceed from thoſe which are more diſtant; ſo that when the objects are very remote, their picture on the retina is eaſily obliterated, by the vigorous and lively impreſſions made by thoſe that are nearer. But when the intermediate ones emit a feeble light, when compared to that which proceeds from the more remote ones, theſe will form a diſtinct picture on the retina, and become perfectly viſible.

The extent of viſion is not only limited by the light of the ambient medium, which enters the eye with the pencils of light that proceed from ſurrounding objects; but it is further impeded by the heterogeneous particles that are conſtantly floating in the air: theſe, by their opacity and reflective power, form a kind of veil, that obſcures the viſion of remote objects; and the more the medium is loaded with theſe particles, and the more remote the object is from the ſpectator, the more obſcure and indiſtinct it will appear, and the limits of viſion be more confined.

The exhalations which continually riſe from the earth, augment this obſcurity, and render the air leſs tranſparent, eſpecially near the earth: the celeſtial bodies generally, therefore, appear more obſcure when near the horizon, than when they are at a greater elevation; becauſe, in the firſt caſe, they are ſeen through that part of the atmoſphere which is contiguous to the ſurface of the earth; but in the latter, through a part which is at a greater diſtance.

Every one knows, that objects at a given diſtance are more diſtinctly ſeen, and are viſible at a greater diſtance in clear, than in foggy weather: Thus early in a clear morning, and when the air is free from vapours, and not much enlightened, a hill or a head-land is viſible at a great diſtance; but as the day advances, the land becomes more obſcure, till at length, by the great opacity of the intervening vapour, and the light reflected by it to the eye, the object becomes leſs and leſs perceptible, and at laſt totally diſappears. Hills, and other high lands, are ſeen more diſtinctly in the morning, partly from this circumſtance, that by their elevation they are more illuminated than the parts intervening between them and the ſpectator.

But the obſcurity ariſing from the exhalations is not the leaſt part of the inconvenience they occaſion; the riſing exhalations have a kind of undulating motion, like that of ſmoke or ſteam, ſo that objects ſeen through them appear to have a tremulous or dancing motion, which is ſenſible even to the naked eye. If diſtant objects be viewed on a hot ſummer's day, this effect is ſo ſenſible in teleſcopes, as to render them entirely uſeleſs for terreſtrial objects, when they augment apparent magnitude more than eighty times.

From this want of tranſparency in the atmoſphere, ariſes that gradual diminution in the light of objects, which painters call the aerial perſpective, by which they endeavour to give that degradation of colour, and indiſtinctneſs of outlines, peculiar to objects at a diſtance: for if the air were perfectly tranſparent, an object would be equally luminous at all diſtances, becauſe the viſible area and the denſity of light decreaſe in the ſame proportion.

Another cauſe which limits the extent of viſion, and for the removal of which optical inſtruments are more particularly adapted, is their ſmallneſs in proportion to their diſtances: for excepting in the caſe of luminous objects ſeen in the dark, it is neceſſary that an image on the retina ſhould have ſome determinate magnitude, in order to become perceptible; thus a houſe may be ſeen at a conſiderable diſtance, but we muſt approach nearer before the windows are diſcernible, and nearer ſtill to diſtinguiſh the bricks.

It is not eaſy to determine with accuracy the quantity of the *minimum viſibile*, or the angle that is ſubtended by the ſmalleſt viſible object. Mr. Harris has inferred, from ſeveral experiments, that objects are ſeldom viſible under an angle leſs than 40 ſeconds, and at a medium not leſs than two minutes.

A ſimple object, as a white or black ſquare, upon the oppoſite colour, is perceivable under a leſs angle than the parts of a compound one. The more objects differ in colour, the more eaſily we can diſtinguiſh their ſeveral impreſſions on the retina: different degrees of light on the ſame object will render it viſible at different diſtances, and under different angles: indeed the moſt general cauſe of the non-viſibility of objects, is the want of ſufficient light in the pencils that proceed from them; ſeveral contiguous objects are ſcarce diſcernible one from the other, unleſs they each ſubtend angles that are not leſs than four minutes.

A long ſlender object is viſible under a ſmaller angle than a ſquare object of the ſame breadth: a ſlender object, as a line, may be conſidered as conſiſting of ſeveral ſquares joined together; and though one of theſe ſquares may be too ſmall to be ſeen, yet the pencils of light coming from each of them being contiguous, and ſtriking at the ſame time upon the retina, are capable, by their united ſtrength, to awaken the viſive faculty, and ſo to render the objects viſible from whence they came. For the ſame reaſon, *a ſmall object in motion* is eaſier diſcerned than if at reſt, and may be viſible in the one caſe, though not in the other. A ſmall ſtar, by day or twilight, that cannot be eaſily ſeen through a teleſcope directed to it, will become viſible by ſhaking or moving the teleſcope.

There is a great difference in the degree of ſenſibility of different eyes. We have been told of perſons ſeeing a ſatellite of Jupiter without the aſſiſtance of glaſſes: a circumſtance that to many appears incredible. But when we conſider how much the various circumſtances of light affect viſion, and how much further our ſight is extended at ſome favourable opportunities than at others, theſe extraordinary accounts may be the more readily credited.

The following calculation of M. de la Hire will give ſome idea of the extreme ſenſibility of the optic nerves. The ſail of a windmill, ſix feet in diameter, may be eaſily ſeen at the diſtance of 4000 toiſes, and the eye being ſuppoſed to be an inch in diameter, the picture of this ſail at the bottom of the eye will be the eight thouſandth part of an inch. This ſhews with what wonderful accuracy the rays of light are refracted by the eye, ſo that a pencil of rays coming from one point of the object, ſhall meet in a point on the retina, ſo as not to deviate the eight thouſandth part of an inch.

If an object be held too cloſe to the eye, it becomes indiſtinct, and the more ſo the cloſer it is held, notwithſtanding it's apparent magnitude is thereby increaſed, and a very ſlender object will become totally inviſible.

To the generality of eyes, the neareſt diſtance of diſtinct viſion is about ſeven or eight inches; at this diſtance they commonly read a ſmall print, and examine all minute objects. It is true ſome eyes can ſee ſmall objects beſt at the diſtance of ſix, four, and even three inches; and ſome again at twelve, fifteen, or twenty inches; but theſe are only particular caſes, and do not, therefore, affect the preſent inquiry.

A globular object that is leſs than $\frac{1}{650}$ inch in diameter, is, to the generality of eyes, totally inviſible: and, excepting in few caſes, an object cannot be ſeen that is leſs than $\frac{1}{430}$ inch in diameter; an object of that breadth ſubtending an angle of 1 *min.* at the diſtance of 8 inches from the eye. But when the field, on which the object is placed, is nearly of the ſame colour with it, we cannot ſee it under an angle leſs than about 4 *min.*. In ſuch circumſtances the ſmalleſt viſible object is not leſs than $\frac{1}{100}$ of an inch in diameter. At a medium, the ſize $\frac{1}{300}$ inch diameter is the ſize of the leaſt globular object diſcernible by the naked eye.

OF DISTINCT AND INDISTINCT VISION.

It will be proper in this place to explain, with more accuracy, what is meant by diſtinct viſion, and what is the difference between ſeeing an object diſtinctly, and ſeeing it clearly; as the clearneſs or brightneſs with which an object is ſeen, is often confounded with diſtinct viſion.

We ſee an object *clearly*, when it is ſufficiently illuminated, to enable us to form a general idea of it's figure, and diſtinguiſh it from other objects: we ſee it *diſtinctly*, when the outlines of it are well defined, when we can diſtinguiſh the parts of it, and determine their colour and ſituation. Thus we may be ſaid to ſee a diſtant object *clearly*, when we can perceive that it is a tower; but to ſee it *diſtinctly*, we approach ſo near as to be able to determine not only it's general outline, but to diſtinguiſh the parts of which it is compoſed.

This may be made more evident, by adverting to the experiment of the dark chamber, in which we ſhall find a conſiderable difference between the diſtinctneſs and brightneſs of the picture; and learn, that a confuſion of the parts is not the ſame thing with obſcurity.

For the picture may be diſtinct in all it's parts; the rays which come from one and the ſame point in the object, may be exactly collected into one and the ſame point upon the paper; and yet, if but few rays paſs through the lens, and conſequently the ſpace where the picture is painted ſhould be but faintly enlightened, this picture, though it is diſtinct, will be faint and obſcure. On the other hand, though the picture be confuſed, either becauſe the paper is placed at an improper diſtance from the lens, or for any other cauſe; yet if many rays paſs through the lens, and ſtrongly illuminate the paper, the picture, notwithſtanding the want of diſtinctneſs, will be a bright one.

The brightneſs or clearneſs with which an object is ſeen, depends principally on the following circumſtances.

1. On the quantity of light proceeding from the object to the eye; and this is in a great meaſure regulated by the diſtance, for the intenſity of

light diminiſhes in an inverſe ratio to the ſquare of the diſtances.

2. It depends on the colour of the object itſelf, and of thoſe objects which ſurround it.

3. On the manner in which the light falls upon the object, and is reflected from it.

4. On the aperture of the pupil, for the wider this is, the greater will be the number of rays that are tranſmitted to the retina.

5. On the tranſparency and purity of the humours of the eye, and the ſoundneſs of the reſt of the viſive parts.

6. On the tranſparency of the atmoſphere.

When all theſe circumſtances concur, an object will appear bright and clear; but leſs ſo, in proportion as any of them are wanting. In order, however, to obtain diſtinct viſion, it is requiſite, not only that the object be ſufficiently illuminated, but alſo that the ſeveral pencils, on their arrival at the retina, ſhould be ſeparate, and not mixed together; and when this is not the caſe, the outlines of the object and it's parts will appear faint, hazy, and ill-defined. We may, therefore, conſider the *following conditions as neceſſary towards obtaining diſtinct viſion.*

1. The objects ſhould be ſufficiently illuminated: now all other circumſtances being the ſame, the nearer an object is, and the brighter it's colour, the more light the eye receives from it; this is one reaſon why near objects are more diſtinctly ſeen than thoſe that are more remote.

2. The geometrical image of objects ſhould fall either upon the retina, or very near it, and theſe images ſhould be ſufficiently large, otherwiſe the parts of the object cannot be diſtinctly perceived: the want of ſize in this image is alſo a cauſe of the indiſtinctneſs of remote objects.

3. It is alſo requiſite that the eye be in perfect order, and it's humours tranſparent, in order that the impreſſions of light may be lively and diſtinct.

In a given eye, and a given diſpoſition of that eye, an image upon the retina will be moſt perfect when the object is at ſome determinate diſtance from the eye; and it is near this point or place, that objects, if they are not too ſmall, will be diſtinctly ſeen. An object at a greater or leſs diſtance, will have it's image either before or behind the retina; and in either caſe, if the diſtance of the image from the retina be conſiderable, the viſion will be indiſtinct.

Dr. Jurin has, however, ſhewn that it is not neceſſary to diſtinct viſion, that the images of objects, or the points of union of the rays, be preciſely upon the retina, there being ſome latitude both before and behind the retina, within which, whatever images be formed, the viſion will be equally diſtinct; and this latitude will be greater or leſs, according as the viſual angles ſubtended by the reſpective objects, are greater or leſs.

Let a printed page, in which there are letters of three or four different ſizes, be placed at ſuch a diſtance, that every ſort of print may, without any ſtraining or effort of the eye, be perfectly diſtinct; in this caſe it may be reaſonably preſumed, that the images of the ſeveral letters fall upon the retina. If the printed leaf be brought gradually nearer and nearer, the ſmalleſt print will firſt begin to be confuſed, whilſt the larger remains as diſtinct as before: by advancing it ſtill nearer, the ſmaller print will become more confuſed, the next ſize above it a little confuſed, whilſt the large print is ſtill as legible as before; and ſo through ſeveral degrees, till the whole is in confuſion.

The ſame experiment may be made the contrary way, by uſing a pair of ſpectacles, of a proper

convexity,

convexity. From hence it is evident, that we may have diſtinct viſion, when the focuſes of the pencils are at ſome diſtance, either before or behind the retina, and that the larger the object, the greater is this latitude.

But as in this caſe the pencils from every point either meet before they reach the retina, or tend to meet beyond it, the light that comes from them muſt cover a circular ſpot upon it, and will, therefore, paint the image larger than perfect viſion would repreſent it: and conſequently, every object, placed either too near or too remote for perfect viſion, will appear larger than it is, by a penumbra of light, cauſed by the circular ſpaces, which are illuminated by pencils of rays proceeding from the extremities of the objects. Theſe circular ſpaces are called circles of diſſipation. This accounts for ſhort-ſighted perſons finding near objects appear rather magnified, when they uſe a concave that is not ſo deep as that to which they are accuſtomed.

On account of theſe penumbræ, it is clear that two ſtars will appear to be nearer than they really are; and if they be really very near, will appear to be but one, but brighter than either of them taken alone: ſo that the two ſtars will have the ſame appearance as if one brighter ſtar appeared in the middle of the ſpace occupied by two ſtars.

When objects are large, they will appear tolerably diſtinct at a much leſs diſtance than ſmall objects, becauſe the penumbræ will not interfere ſo much. For this reaſon, a large print may be read much nearer the eye than a ſmall one; the former will appear only ill-defined, but ſufficiently diſtinct, when the latter is quite indiſtinct, the penumbra of one letter interfering with that of another.

It is very difficult to aſcertain preciſely the natural diſtance of diſtinct viſion, or that diſtance at which the eye, without any ſtrain or effort, is ſuited to ſee objects diſtinctly. If we ſuppoſe this diſtance to be that at which we uſually read a large fair print, this will be about fifteen or ſixteen inches, and leſs it cannot be, as we are rather more concerned with large objects than the letters of a book; and when we view objects nearer, it is on account of their minuteneſs: nor is it probable that the diſtance can be many feet, as, in order to examine objects, we are always deſirous to have them near the eye, except they are very large. The neareſt diſtance of diſtinct viſion is in general computed to be about ſeven or eight inches from the eye. *That point in any object, to which the optic axis is directed, is ſeen more diſtinctly than the reſt.* The truth of this poſition is confirmed by every one's experience: if we turn our eyes directly toward one particular part of an object ſo as to look ſteadily at it, we may indeed, if the object be not very large, ſee all the reſt of it at the ſame time; but this part will appear more diſtinct than the reſt: but looking ſteadily at an object is turning our optic axis towards it.

OF THE CHANGE IN THE CONFORMATION OF THE EYE FOR DISTINCT VISION, AT DIFFERENT DISTANCES.

As a ſhip requires a different trim for every variation of the direction and the ſtrength of the wind, ſo, if we may be allowed to borrow that word, the eyes require a different trim for every degree of light, and for every variation in the diſtance of the object, while it is within certain limits. The eyes are trimmed for a particular object, by contracting certain muſcles, and relaxing others; as the ſhip is trimmed for a particular wind, by drawing ſome ropes, and ſlackening others. The ſailor learns this trim of his ſhip, as we learn the trim of our eyes, by experience.*

A ſhip, although it be the nobleſt machine that human art can boaſt, is far inferior to the eye; for it requires art and ingenuity to navigate her, and the ſailor muſt know what ropes to pull, and which to ſlacken, to accommodate her to a particular wind. But the eye is fabricated with ſuch ſuperior wiſdom, and the principles of it's motion ſo contrived, that it requires no art nor ingenuity to ſee by it: we have not to learn what muſcles we are to contract, nor which we are to relax, in order to fit the eye to a particular diſtance of the object.

But although we are not conſcious of the motions we perform, in order to fit the eyes to the diſtance of the object, we are conſcious of the effort employed in producing theſe motions, and probably have ſome ſenſation which accompanies them, and to which we give as little attention as to many other ſenſations; and thus a ſenſation, either previous or conſequent upon that effort, comes to be conjoined with the diſtance of the object which gave occaſion to it, and by this conjunction becomes one of the ſigns of that diſtance.

That we are capable of viewing objects with nearly equal diſtinctneſs, though they be placed at conſiderable diſtances from each other, is evident; but the alteration which takes place in the eye for this purpoſe, or the mechaniſm by which this effect is produced, is not eaſily aſcertained.

It ſeems clear from the firſt view of the ſubject, that when ſeveral objects are at different diſtances before us, they will not appear equally diſtinct at the ſame time. Leſt it ſhould be ſuſpected that the indiſtinctneſs in this caſe may be owing to the impreſſions not being made upon the correſponding fibrils of the two retinas, let us make a trial with one eye alone, while the other is ſhut; thus place two ſmall objects, as two pins, one behind the other, and let the one be at a foot, and the other at about ſix inches diſtance from the eye. Either of theſe objects, when looked at attentively, will appear diſtinct; but the other, at the ſame time, although it be in the axis of the eye, will be confuſed. And from hence it is very clear, that the ſame conformation of the eye is not adapted for diſtinct viſion at all diſtances, and that the eye by ſome means changes it's conformation, ſo as it may be better ſuited for viſion at different diſtances.

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* Reid's Inquiry into the Human Mind.

In a ſimilar manner to the foregoing experiment, if the eye looks attentively upon the little ſcratches or particles of duſt upon a window-glaſs, the objects without doors will be indiſtinct; and when we look at the external objects, the opake particles upon the glaſs, which before were diſtinct, will now be confuſed. It alſo frequently happens, that when we firſt look at an object, it will appear very confuſed, which confuſion will vaniſh by degrees, and in a little time the object will become quite diſtinct.

In like manner, if after poring ſome time on a book, we ſuddenly look at objects farther off, they will at firſt appear confuſed, and become diſtincter by degrees. A ſimilar indiſtinctneſs takes place, when from looking at remote objects, we ſuddenly look at one that is near. To what can we attribute theſe phenomena, but to a change in the conformation of the eye for viſion at theſe different diſtances? a change which requires ſome ſmall time for it's performance. It cannot be owing to the laſt impreſſion on the eye not being obliterated; for in that caſe, the ſame confuſion would be obſervable upon ſhifting the eye from one page of a book to the other.

Theſe phenomena are ſtronger when they happen without our thinking upon them; for when we make the experiment on purpoſe, and the mind is already prepared for what is to happen, it has time in part to fruſtrate our deſign; the more ſo, as theſe changes are ſomewhat painful.

Authors are much divided in their opinions concerning the change that is made in the conformation of the eye, to procure diſtinct viſion at different diſtances; ſome thinking it to be a change in the length of the eye, others that it is a change in the figure or poſition of the cryſtalline humour, others that it is a change in the cornea. The authors of each opinion have their objections to all the reſt, and perhaps the truth may lie among them all. As the rays of light ſuffer a greater refraction at the cornea than they do afterwards, it is plain that a leſs change, as to quantity, in the radius of the cornea, will effect the buſineſs, than would be ſufficient in any other part of the eye: but at the ſame time it muſt alſo be confeſſed, that moſt perſons who have been couched for cataracts, are obliged to have glaſſes of different convexities, in order to have diſtinct viſion at different diſtances; from whence it ſeems neceſſarily to follow, that the cryſtalline humour is concerned in changing the conformation of the eye. Perhaps the cornea, and the cryſtalline, if not ſome other parts of the eye beſides, may contribute to produce this effect: and in order to obtain diſtinct viſion at a nearer diſtance, at the ſame time the cornea is rendered more convex, the axis of the eye may be a little lengthened, the cryſtalline made more convex and brought forwarder; all which changes conſpire to the ſame end; and the contrary for obtaining viſion at a greater diſtance.

It has been ſhewn by writers on optics, that if an object be viewed diſtinctly at three different diſtances from the eye, the firſt of which may be the leaſt diſtance at which it can be viewed diſtinctly, the ſecond double the firſt, and the third infinite, the alterations in the conformation of the eye, neceſſary for viewing an object diſtinctly at the firſt and ſecond diſtances, whoſe difference is but ſmall, are as great as thoſe that are neceſſary for the ſecond and third, whoſe difference is infinite.

Hence, if a ſhort-ſighted perſon can read a ſmall print diſtinctly, at two different diſtances, whereof the larger is but double the leſſer, as great alterations are made in his eyes, as in one whoſe eyes are perfect, and that can ſee diſtinctly at all intermediate diſtances, between infinity and the largeſt of the two former diſtances. For the ſame reaſon, a ſhort-ſighted perſon can ſee diſtinctly at all diſtances, with a ſingle concave of a proper figure; for the cauſe of ſhort-ſightedneſs is not a want of power to vary the conformation of the eye, but that the whole quantity of refractions is always too great for the diſtance of the retina from the cornea.

We may hence alſo clearly perceive why our eyes are ſo often fatigued in looking at near objects; for in this caſe, the muſcles of the eyes, and the ligamentum ciliare, are obliged to make a conſiderable effort, to give the eyes the neceſſary conformation; which effort being greater in proportion as the object is nearer, muſt be painful and laborious when the object is very nigh.

When the eye has been attentively fixed on an object at ſome determined diſtance, it cannot immediately ſee another object diſtinctly; whether it be at a greater or leſſer diſtance, it appears confuſed and imperfect, till the eye has adapted itſelf to the diſtance at which the object is placed.

OF THE PUPIL OF THE EYE, AND OF IT'S MOTIONS.

In ſpeaking of the ſtructure of the eye, we have ſhewn that the uvea has a ſmall round hole nearly in the middle, called the *pupil*, through which the rays muſt all paſs before they can get to the bottom of the eye, and paint the images of objects on the retina. The conſideration of the various affections of this part of the eye, will be found of great importance, both to the vender and purchaſer of ſpectacles; for upon the ſtate and aperture of the pupil, the requiſite degree of magnifying power very much depends.

The author of nature has proportioned the magnitude of the pupil, ſo that it may beſt anſwer the purpoſes of viſion, and the ſenſibility of the retina: if it were too large, the retina would be fatigued, and hurt by the great quantity of light. Hence it is that thoſe creatures cannot bear the light of day, which, in order to ſearch for and procure their food at night, have the pupil of their eyes very large. Further, if this aperture had been much larger than it really is, the eye would not have been a dark cell, and ſo much adventitious light would have entered, as to render the picture upon the retina obſcure and indiſtinct: for as in the camera obſcura, the pictures are moſt lively and perfect when all the light is excluded, but what comes from the object, and ſerves to form the picture; ſo it is with our eyes; the picture on the retina is moſt perfect when all the extraneous light is excluded, and none mixes with the picture, but what tends to it's formation.

On the other hand, if the pupil had been very ſmall, it would not have admitted a ſufficient quantity of light; the impreſſion on the retina would have been weak, and the picture faint and obſcure;

when the pupil is very ſmall, convex glaſſes are neceſſary, in order to increaſe the quantity of light.

All animals have a power of contracting and dilating the pupil of their eyes. The natural ſtate appears to be that of dilatation, and the contraction a ſtate of violence, produced by an effort originating in the mind. When the light is too ſtrong, or the object too bright, we contract the pupil, to intercept that part of the light which would injure the eye; but when the light is weak, we dilate the pupil, that more light may enter the eye. If a perſon look towards the ſun, you will obſerve the pupil become exceeding ſmall; but if he turns his eyes from the light, and be gradually brought into a dark place, you will obſerve the pupil to dilate, in proportion as the light becomes more faint and obſcure.

There are alſo other circumſtances which will cauſe the pupil to contract, as when the object is nearer the eye than the limits of diſtinct viſion: for in this caſe, the pencils of rays proceeding from the object are too diverging to be united in correſponding points on the retina; but by contracting the pupil, many of the rays are excluded, and the picture is rendered more diſtinct. It is for this purpoſe, that many ſhort-ſighted perſons contract a habit of corrugating their eyebrows in reading, a habit which would be prevented by the uſe of concave ſpectacles.

Dr. Jurin has ſhewn, that the contraction of the pupil does, in general, depend more upon the ſtrength of the light, than on the ſenſation of confuſion in the object. Let any perſon take a book by day-light, and ſtand near the middle of a room, with his back to the light, and then hold the book ſo near that the letters may appear indiſtinct, but not ſo much ſo, but that they may be read, though with difficulty; on turning towards the light, it will be read with more eaſe. Again, holding the book at the ſame diſtance, go into the darkeſt part of the room, and ſtanding with your back to the light, you will find the book not at all legible; but on coming to the window, with your face to the light, you will be able to read with eaſe and diſtinctneſs. A perſon who has uſed ſpectacles for ſome years, will in the ſun-ſhine be able to read without them.

When we have been for ſome time in a place much illuminated, or if the eye has been too long expoſed to a reſplendent object, and then views objects that are leſs ſo, or goes into a darker place, the ſight will for a little time be impaired, and the eye unable to perform it's proper functions. The ſame will alſo happen from the contrary circumſtances, if we go from a faint light into one that is much brighter; in either caſe the pupil has not time to conform itſelf to the ſudden,* but neceſſary change, for ſeeing diſtinctly under the new circumſtances. From hence we may infer, that very opake ſhades round a candle, inſtead of preſerving and protecting the eye, muſt be neceſſarily prejudicial to it. A moderate degree of opacity in the ſhade, as that of thick paper, may, by leſſening the degree of light, be uſeful to eyes which are inflamed, or have a tendency to inflammation.

There is a kind of ſympathy, or concord, in the motion of the pupils of both eyes, ſo that when one is contracted, the other contracts alſo; when one is dilated, the other alſo dilates, though neither the dilatation nor contraction are equal. Many groſs overſights have ariſen, and ſome dangerous miſtakes have been made, by oculiſts, according to Porterfield, from their not attending to this fundamental law concerning the pupil.

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* This is what Porterfield and ſome others ſay; but from other experiments, the pupil is never ſo contracted as in the caſe of going ſuddenly from a faint to a bright light: the contraction is inſtantaneous. The effects, therefore, ſpoken of above, muſt be referred to the different ſtates of the ſenſibility of the retina.

From this expanding and contracting power of the eye, we may learn, why the eye ſees beſt when ſurrounded with darkneſs; for the pupil, by dilating, accommodates itſelf as much as poſſible to the quantity of light, dilating conſiderably when the eye is in darkneſs, and, *cæteris paribus*, objects are ſeen moſt clearly when the pupil is moſt dilated. Beſides, when the eye is in the dark, the picture on the retina is neither confuſed nor diſturbed by adventitious rays: hence, thoſe who are in a very bright light, when they want to diſtinguiſh accurately a diſtant object, either depreſs the eyebrows, or apply the hand to the forehead: hence alſo, a perſon, by placing himſelf in the dark, and employing a long tube, will form a ſpecies of teleſcope, producing a greater effect than might at firſt be conceived: it was on this principle that the ancients uſed a deep pit, in order to ſee the ſtars in the day-time. From hence we alſo learn, why a perſon from within a chamber can perceive the objects that are without, while thoſe that are out of doors cannot ſee the objects that are within; for when we are out of doors, the pupil is contracted, and only a ſmall portion of the light that is reflected from the objects within the chamber, can paſs to the retina; while on the contrary, thoſe within have the pupil more dilated, and the objects that are without are alſo more ſtrongly illuminated; beſides which, their view of objects is not ſo much obſtructed by the reflection of the window-glaſs.

It is ſurprizing how far the eye can accommodate itſelf to darkneſs, and make the beſt of a gloomy ſituation. When firſt taken from the light, and brought into a dark room, all things diſappear;

or if any thing is ſeen, it is only the remaining radiations that ſtill continue in the eye; but after a very little time, the eye takes advantage of the ſmalleſt ray, which is confirmed by the following curious account, related by Mr. Boyle. In the time of Charles the firſt, there was a gentleman, who, ſharing in his worthy maſter's misfortunes, was forced abroad; at Madrid, in attempting to do his king a ſignal ſervice, he failed; in conſequence of this, he was confined in a dark and diſmal dungeon, into which the light never entered, and into which there was no opening but by a hole at the top, down which the keeper put his proviſions; preſently cloſing it again. The unfortunate loyaliſt continued for ſome weeks in this dark dungeon, quite diſconſolate; but, at laſt, began to think he ſaw ſome glimmering of light: this dawn of light increaſed from time to time, ſo that he could not only diſcover the parts of his bed, and ſuch other large objects, but, at length, he could perceive the mice that frequented his dungeon, to eat the crumbs that fell upon the ground. When ſet at liberty, he could not, for ſome days, venture to leave his cell, leſt the brightneſs of the light ſhould blind him; but was obliged to accuſtom his eyes, by ſlow and gradual degrees, to the light of the day.

OF IMPERFECT SIGHT.

There is no branch of ſcience, of which it is more important that a general knowledge ſhould be diffuſed, than that part which treats of the various imperfections of ſight, and the remedies for them. To relieve an organ which is the ſource of the moſt refined pleaſure, is certainly a deſirable object: to enable thoſe who are in want of aſſiſtance, to determine whether ſpectacles will be advantageous or detrimental, and what kind will beſt ſuit their ſight; and ſo inſtruct thoſe who already uſe glaſſes, that they may diſcover whether thoſe they have choſen are adapted to the imperfection of their ſight, or are ſuch as will increaſe their complaint, and weaken their eyes; are ſubjects worthy the conſideration of every individual, and conſtitute the principal buſineſs of the remainder of this Lecture: to this end I ſhall, in the firſt place, explain what I mean by an imperfection of ſight.

The ſight is relatively imperfect, when we cannot ſee an object diſtinctly in a common light, and at all the uſual diſtances at which it is obſerved by an eye in a perfect ſtate.

In this ſenſe, both the long and ſhort-ſighted are ſaid to have an imperfect ſight. The ſhort-ſighted ſee diſtant objects confuſedly, thoſe that are near at hand diſtinctly; their ſight is therefore defective with reſpect to diſtant objects: on the other hand, the long-ſighted ſee diſtant objects diſtinctly, near objects confuſedly.

An imperfect ſight is occaſioned by a confuſion in the image formed upon the retina; this happens whenever all the rays that proceed from any one point of an object, are not united again in one, but fall on different points of the retina: or whenever ſeveral pencils of light, from different points of an object, terminate upon one point of the image. This ſpecies of confuſion takes place both in long and ſhort-ſighted eyes.

OF OLD OR LONG-SIGHTED EYES.

To detail thoſe circumſtances which are, in general, marks of advancing age, and always of partial infirmity, muſt be ever unpleaſant, and would be equally unneceſſary, if it were not the mean of leſſening the inconveniences attendant on thoſe ſtages of life.

By the long-ſighted, remote objects are ſeen diſtinctly, near ones confuſedly; and in proportion as this defect increaſes, the nearer objects become more indiſtinct, till at length it is found almoſt impoſſible to read a common-ſized print without aſſiſtance. An imperfect and confuſed image is formed upon the retina, becauſe the rays of light that come from the ſeveral points of an object, at an ordinary diſtance, are not ſufficiently refracted, and therefore do not meet upon the retina, but beyond it.

Various are the cauſes which may occaſion this defect; if the convexity of the cornea be leſſened, or if either ſide of the cryſtalline becomes flatter, this effect will be produced; if the retina be not ſufficiently removed from the cornea or cryſtalline, or if the retina be too near the cornea or cryſtalline, it will give riſe to the ſame defect, as will alſo a leſs refractive power in the pellucid parts of the eye; in like manner, too great a proximity of the objects, will prevent the rays from uniting till they are beyond the retina; but if all theſe cauſes concur together, the effect is greater. This defect is, however, in general, attributed to a ſhrinking of the humours of the eye, which cauſes the cornea and cryſtalline to loſe their original convexity, and to become flatter; the ſame cauſe will bring the retina too near the cornea.

By one or other of theſe cauſes, thoſe who were accuſtomed in their youth to read a common ſize print, at about twelve or fourteen inches diſtance from their eyes, are obliged to remove the book to two or three feet before they can ſee the letters diſtinctly, and read with comfort. But in proportion as the object is removed from the eye, the image thereof on the retina becomes ſmaller' and conſequently ſmall objects will not always be perceivable at that diſtance, to which thoſe in this ſtate find it neceſſary to remove them, in order to attain any degree of diſtinct viſion: the further alſo the object is removed, the leſs light will enter the eye, and the image will, of courſe, be fainter.

Hence, thoſe who are long-ſighted require more light to enable them to read, than they did while their eyes were in their perfect ſtate; and this not only becauſe they are obliged to remove the book to a greater diſtance, but becauſe the pupil of their eye is ſmaller, and therefore a greater intenſity of light is neceſſary to produce a ſufficient impreſſion on the retina, and compenſate for the defect by a greater ſplendor and illumination of the object.

Increaſing years have a natural tendency to bring on this defect, and earlier among thoſe who have made the leaſt uſe of their eyes in their youth; but whatever care be taken of the ſight, the decays of nature cannot be prevented: the humours of the eye will gradually waſte and decay, the refractive coats will become flatter, and the other parts of the eye more rigid and leſs pliable; thus the latitude of diſtinct viſion will become contracted: it is alſo highly probable, that the retina and optic nerve loſe a portion of their ſenſibility.

Though it is in the general courſe of nature, that this defect ſhould augment with age, yet there are not wanting inſtances of thoſe who have recovered their ſight at an advanced period, and, have been able to lay aſide their glaſſes, and read and write with pleaſure, without any artificial aſſiſtance. Among many cauſes which may produce this effect, the moſt probable is, that it generally ariſes from a decay of the fat in the bottom of the orbit; the preſſure in this part ceaſing, the eye expands into ſomewhat of an oval form, and the retina is removed to a due focal diſtance from the cryſtalline.

It is a certain and very important fact, that long-ſightedneſs may be acquired; for countrymen, ſailors, and thoſe that are habituated to look at remote objects, are generally long-ſighted, want ſpectacles ſooneſt, and uſe the deepeſt magnifiers: on the other hand, the far greater part of the ſhort-ſighted are to be found among ſtudents, and thoſe artiſts who are daily converſant with ſmall and near objects; every man becoming expert in that kind of viſion, which is moſt uſeful to him in his particular profeſſion and manner of life: thus the miniature painter, and engraver, ſee very near objects better than a ſailor; but the ſailor perceives diſtant objects better than they do; the eye in both caſes endeavouring to preſerve that configuration to which it is moſt accuſtomed. In the eyes, as well as other parts of the body, the muſcles, by conſtant exerciſe, are enabled to act with more eaſe and power, but are enfeebled by diſuſe; the elaſtic parts alſo, if they are kept too long ſtretched, loſe part of their elaſticity; while on the other hand, if they be ſeldom exerciſed, they grow ſtiff, and are not eaſily diſtended. From the conſideration of theſe facts, we may learn, in a great meaſure, how to preſerve our eyes; by habituating them occaſionally to near as well as diſtant objects, we may maintain them longer in their perfect ſtate, and be able to poſtpone the uſe of ſpectacles for many years; but we may alſo infer from the ſame premiſes, that there is great danger, when the eyes are become long-ſighted, of deferring too long the uſe of ſpectacles, or uſing thoſe that magnify too much, as we may by either method ſo flatten the eye, as to loſe entirely the benefits of naked viſion. It may not be improper in this place to remark, that the long-ſighted eye is much more liable to be injured by too great a degree of light, than thoſe that are ſhort-ſighted.

Objects that appear confuſed to the long-ſighted, will be rendered more diſtinct, if they view them through a ſmall hole, ſuch as that made by a pin in a card, becauſe it excludes thoſe diverging rays which are the principal ſource of confuſion; but as it, at the ſame time, intercepts a conſiderable portion of the light, it is by no means an adequate remedy. The beſt relief they can obtain is from convex glaſſes, for by theſe the rays of light that proceed from the object, are ſo refracted, as to fall upon the retina, in the ſame manner as if they iſſued from a diſtant point. Spectacles afford two advantages, for they not only render the picture of objects diſtinct upon the retina, but they alſo make it ſtrong and lively.

OF SPECTACLES.

Spectacles reſtore and preſerve to us one of the moſt noble and valuable of our ſenſes; they enable the mechanic to continue his labour, and earn a ſubſiſtence by the work of his hand, till the extreme of old age. By their aid the ſcholar purſues his ſtudies, and recreates his mind with intellectual pleaſures, and thus paſſes away days and years with delight and ſatisfaction, that might otherwiſe have been devoured by melancholy, or waſted by idleneſs.

As ſpectacles are deſigned to remedy the defects of ſight, it is natural to wiſh, that the materials of which they are formed ſhould be as perfect as the eye itſelf; but vain is the wiſh, for the materials we uſe, like every thing human, are imperfect, and yet we may deem ourſelves happy, to have in glaſs a ſubſtitute ſo analagous to the humours of the eye, a ſubſtance which gives new eyes to decrepid age, and enlarges the views of philoſophy. The two principal defects are, ſmall threads or veins in the glaſs, and minute ſpecks. The threads are moſt prejudicial to the purpoſes of viſion, becauſe they refract the rays of light irregularly, and thus diſtort the object, and fatigue the eye; whereas the ſpecks only leſſen the quantity of light, and that in a very ſmall degree.

GENERAL RULES FOR THE CHOICE OF SPECTACLES.

The moſt general, and perhaps the beſt rule that can be given, to thoſe who are in want of aſſiſtance from glaſſes, in order ſo to chooſe their ſpectacles, that they may ſuit the ſtate of their eyes, is to prefer thoſe which ſhew objects neareſt their natural ſtate, neither enlarged nor diminiſhed, the glaſſes being near the eye, and that give a blackneſs and diſtinctneſs to the letters of a book, neither ſtraining the eye, nor cauſing any unnatural exertion of the pupil.

For no ſpectacles can be ſaid to be properly accommodated to the eyes, which do not procure them eaſe and reſt; if they fatigue the eyes, we may ſafely conclude, either that we have no occaſion for them, or that they are ill made, or not proportioned to our ſight.

Though, in the choice of ſpectacles, every one muſt finally determine for himſelf, which are the glaſſes through which he obtains the moſt diſtinct viſion; yet ſome confidence ſhould be placed in the judgment of the artiſt, of whom they are purchaſed, and ſome attention paid to his directions.

OF PRESERVERS, AND RULES FOR THE PRESERVATION OF THE SIGHT.

Though it may be impoſſible to prevent the abſolute decay of ſight, whether ariſing from age, partial diſeaſe, or illneſs, yet by prudence and good management, it's natural failure may certainly be retarded, and the general habit of the eyes ſtrengthened, which good purpoſes will be promoted by a proper attention to the following maxims.

1. Never to ſit for any length of time in abſolute gloom, or expoſed to a blaze of light. The reaſons on which this rule is founded, prove the impropriety of going haſtily from one extreme to the other, whether of darkneſs or of light, and ſhew us, that a ſouthern aſpect is improper for thoſe whoſe ſight is weak and tender.

2. To avoid reading a ſmall print.

3. Not to read in the duſk; nor, if the eyes be diſordered, by candle-light. Happy thoſe who learn this leſſon betimes, and begin to preſerve their ſight, before they are reminded, by pain, of the neceſſity of ſparing them; the frivolous attention to a quarter of an hour of the evening, has coſt numbers the perfect and comfortable uſe of their eyes for many years: the miſchief is effected imperceptibly, the conſequences are inevitable.

4. The eye ſhould not be permitted to dwell on glaring objects, more particularly on firſt waking in a morning; the ſun ſhould not of courſe be ſuffered to ſhine in the room at that time, and a moderate quantity of light only be admitted. It is eaſy to ſee, that for the ſame

reaſons, the furniture of a bed ſhould be neither altogether of a white or red colour; indeed, thoſe whoſe eyes are weak, would find conſiderable advantage in having green for the furniture of their bed-chamber. Nature confirms the propriety of the advice given in this rule: for the light of the day comes on by ſlow degrees, and green is the univerſal colour ſhe preſents to our eyes.

5. The long-ſighted ſhould accuſtom themſelves to read with rather leſs light, and ſomewhat nearer to the eye than what they naturally like; while thoſe that are ſhort-ſighted, ſhould rather uſe themſelves to read with the book as far off as poſſible. By this means, both would improve and ſtrengthen their ſight; while a contrary courſe will increaſe it's natural imperfections.

There is nothing which preſerves the ſight longer, than always uſing, both in reading and writing, that moderate degree of light which is beſt ſuited to the eye; too little ſtrains them, too great a quantity dazzles and confounds them. The eyes are leſs hurt by the want of light, than by the exceſs of it; too little light never does any harm, unleſs they are ſtrained by efforts to ſee objects, to which the degree of light is inadequate; but too great a quantity has, by it's own power, deſtroyed the ſight. Thus many have brought on themſelves a cataract, by frequently looking at the ſun, or a fire; others have loſt their ſight, by being brought too ſuddenly from an extreme of darkneſs into the blaze of day. How dangerous the looking upon bright luminous objects is to the ſight, is evident from it's effects in thoſe countries which are covered the greater part of the year with ſnow, where blindneſs is exceeding frequent, and where the traveller is obliged to cover his eyes with crape, to prevent the dangerous, and often ſudden effects of too much light: even the untutored ſavage tries to avoid the danger, by framing a little wooden caſe for his eyes, with only two narrow ſlits. A momentary gaze at the ſun, will, for a time, unfit the eyes for viſion, and render them inſenſible to impreſſions of a milder nature.

The following caſes from a ſmall tract on the "*Fabric of the Eye*," are ſo applicable to the preſent article, as to want no apology for their inſertion here; though if any were neceſſary, the uſe they will probably be of to thoſe whoſe complaints ariſe from the ſame or ſimilar cauſes, would, I preſume, be more than ſufficient.

"A lady from the country, coming to reſide in St. James's-ſquare, was afflicted with a pain in the eye, and a decay of ſight. She could not look upon the ſtones, when the ſun ſhone upon them, without great pain. This, which ſhe thought was one of the ſymptoms of her diſorder, was the real cauſe of it. Her eyes, which had been accuſtomed to the verdure of the country, and the green of the paſture grounds before her houſe, could not bear the violent and unnatural glare of light reflected from the ſtones; ſhe was adviſed to place a number of ſmall orange trees in the windows, ſo that their tops might hide the pavement, and be in a line with the graſs. She recovered by this ſimple change in the light, without the aſſiſtance of any medicine; though her eyes were before on the verge of little leſs than blindneſs."

"A gentleman of the law had his lodgings in Pall-mall, on the north-ſide, his front windows were expoſed to the full noon ſun, while the back room, having no opening, but into a ſmall cloſe yard, ſurrounded with high walls, was very dark;

he wrote in the back room, and uſed to come from that into the front to breakfaſt, &c. his ſight grew weak, and he had a conſtant pain in the balls of his eyes; he tried viſual glaſſes, and ſpoke with oculiſts, equally in vain. Being ſoon convinced, that the coming ſuddenly out of his duſky ſtudy, into the full blaze of ſun-ſhine, and that very often in the day, had been the real cauſe of his diſorder; he took new lodgings, by which, and forbearing to write by candle-light, he was very ſoon cured."

Blindneſs, or at leaſt miſerable weakneſſes of ſight, are often brought on by theſe unſuſpected cauſes. Thoſe who have weak eyes, ſhould therefore be particularly attentive to ſuch circumſtances, ſince prevention is eaſy, but the cure may be difficult, and ſometimes impracticable.

Whatſoever care, however, be taken, and though every precaution be attended to with ſcrupulous exactneſs; yet as we advance in years, the powers of our frame gradually decay; an effect which is generally firſt perceived in the organs of viſion.

Age is, however, by no means an abſolute criterion, by which we can decide upon the ſight, nor will it prove the neceſſity of wearing ſpectacles. For, on the one hand, there are many whoſe ſight is preſerved in all it's vigour, to an advanced old age; while, on the other, it may be impaired in youth by a variety of cauſes, or be vitiated by internal maladies. Nor is the defect either the ſame in different perſons of the ſame age, or in the ſame perſon at different ages; in ſome the failure is natural, in others it is acquired.

From whatever cauſes this decay ariſes, an attentive conſideration of the following rules will enable every one to judge for himſelf, when his ſight may be aſſiſted or preſerved by the uſe of ſpectacles.

1. When we are obliged to remove ſmall objects to a conſiderable diſtance from the eye, in order to ſee them diſtinctly.

2. If we find it neceſſary to get more light than formerly; as for inſtance, to place the candle between the eye and the object.

3. If on looking at, and attentively conſidering a near object, it becomes confuſed, and appears to have a kind of miſt before it.

4. When the letters of a book run one into the other, and hence appear double and treble.

5. If the eyes are ſo fatigued by a little exerciſe, that we are obliged to ſhut them from time to time, and relieve them by looking at different objects.

When all theſe circumſtances concur, or any of them ſeparately take place, it will be neceſſary to ſeek aſſiſtance from glaſſes, which will now eaſe the eyes, and in ſome degree check their tendency to grow flatter; whereas if they be not aſſiſted in time, the flatneſs will be conſiderably increaſed, and the eyes be weakened by the efforts they are compelled to exert.

We are now able to decide upon a very important queſtion, and ſay how far ſpectacles may be ſaid to be *preſervers of the ſight*. It is plain they can only be recommended as ſuch, to thoſe whoſe eyes are beginning to fail; and it would be as abſurd to adviſe the uſe of ſpectacles to thoſe who feel none of the foregoing inconveniences, as it would be for a man in health to uſe crutches to ſave his legs. But thoſe who feel thoſe inconveniences, ſhould immediately take to ſpectacles, which, by enabling them to ſee objects nearer, and by facilitating the union of the rays of light on the retina, will ſupport and preſerve the ſight.

OF COUCHED EYES.

With the diſeaſes of the eye, theſe Lectures have no concern; they have been already well and ably conſidered by profeſſional men; and it is ſcarce neceſſary to obſerve, that in anatomical knowledge, and in the practical operations of ſurgery, England now claims a juſt pre-eminence over other nations.

But among the various diſeaſes of this organ, there is one in which, after the ſurgeon has quitted the patient, glaſſes are neceſſary, to give effect to the operation, and a comfortable ſight of objects to the perſon relieved. This diſeaſe is the cataract, a diſorder affecting the cryſtalline humour of the eye; when the opacity is confirmed, this humour becomes ſo opake, as ſcarcely to admit any rays of light, and prevents their producing their ordinary effects, and conſequently no image of any object is formed, though the retina, and other organs of ſight, are in perfect order. There is no diſorder more deplorable in it's nature and conſequences; deſtructive of the ſight, often beyond the reach of remedy: the hand of the operator is the only hope, and his efforts are ſometimes unſucceſsful.

The cauſe of this diſorder is ſeldom known. Sometimes it has been thought to be brought on by frequent inſpection of the ſun, and ſometimes by looking too long and too often at a bright fire. In early ſtages of the diſeaſe it has been thought to be removed by medicine.* Of the various remedies that have been uſed for this purpoſe, the electrical ſtream is ſuppoſed by many to be the beſt, on account of it's powerful diſcutient properties.

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* Baron de Wenzel, in his Treatiſe on the Cataract, denies that any medicine has power to diſſipate the opake cryſtalline. Mr. Ware, in his tranſlation of this work, aſſents to the truth of the Baron's obſervation, ſo far as is at preſent known; but adds, that many caſes have occurred, under his own inſpection, which prove that the powers of nature are often ſufficient for this purpoſe. Thoſe opacities in particular, which are produced by external

The aſſiſtance the eye receives from the ſurgeon is either by depreſſion of the cryſtalline below the pupil, or extracting the cataract. But as the denſity of the vitreous humour, which ſupplies the place of the cryſtalline, is leſs, the rays of light will be leſs refracted, and not meet at the retina, but at ſome diſtance behind it; the ſight will therefore be imperfect, except the eye be aſſiſted with a proper convex glaſs. There is a circumſtance attending couched eyes, which fully evinces that the change made in our eyes, to accommodate them to the diſtances of objects, muſt be principally attributed to the cryſtalline humour; namely, that one focus is ſeldom ſufficient to enable thoſe who have undergone this operation, to ſee objects at different diſtances. They generally require two pair of ſpectacles, one for near, the other for more diſtant objects. The foci that are uſed lie between 6 and 1½ inches.

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nal violence, he has repeatedly ſeen diſſipated in a ſhort ſpace of time, when no other parts of the eye have been hurt; and in general, in caſes of this deſcription, the cryſtalline humour has been diſſolved; which has been demonſtrated, by the benefit the patient has afterwards derived from adopting the uſe of deeply convex glaſſes. Mr. Ware adds, that inſtances are not wanting, in which cataracts, which were formed without any violence, have been ſuddenly diſſipated, in conſequence of an accidental blow on the eye. For theſe reaſons he entertains a hope, that means may hereafter be diſcovered, by which an opake cryſtalline may be rendered tranſparent, without the performance of any operation whatever. The remedies which have appeared to Mr. Ware more effectual than others, in theſe caſes, have been the application to the eye itſelf of one or two drops of æther, once or twice in the courſe of the day, and the occaſional rubbing of the eye over the lid, with the point of the finger, firſt moiſtened with a weak volatile or mercurial liniment. See Ware's tranſlation of Wenzel's Treatiſe on the Cataract, page 13.

It is not adviſeable to uſe glaſſes too ſoon after the operation; for while the eyes are in a debilitated ſtate, all exertions are not only improper, but alſo very prejudicial.

OF THE SHORT-SIGHTED.

In this defect of the eyes, the images of objects at an ordinary diſtance unite before they arrive at the retina, and conſequently the images formed thereon are confuſed and indiſtinct. This effect is produced either by too great a convexity in the cornea and cryſtalline, or too great a refractive power in the humours of the eye; or the retina may be placed too far; or it may ariſe from a concurrence of all theſe circumſtances.

Thoſe who are ſhort-ſighted can diſtinguiſh ſmaller objects, and ſee clearly a given ſmall object with leſs light than other people: the reaſon is evident, for the nearer the object is, the more light enters the pupil; being alſo more denſe, it's action is more powerful on the retina; hence the ſhort-ſighted can read a ſmall print by moon-ſhine, or in the twilight, when a common eye can ſcarce diſtinguiſh one letter from another.

In a ſtrong light they can ſee a little farther than they do when it is weak; the ſtrength of the light cauſes the pupil of their eyes to contract, and thus removes in ſome degree the indiſtinctneſs of the objects. Upon the ſame principle we may account for the ſhort-ſighted ſo often partly ſhutting their eyelids, from whence they were formerly denominated *myopes*; by this means, they confine the baſes of the pencils of rays which iſſue from the points of an object, and thus contract the circle of diſſipation, and leſſen the indiſtinctneſs of viſion: hence they alſo ſee objects more diſtinctly through a ſmall hole, as that made by a pin in a card.

It is a common obſervation, that the ſhort-ſighted do in general prefer a ſmall print to a large one, and that they uſually write a ſmall hand; for by the proximity the letters are magnified; and, being ſmall, they take in a greater number at one view; they hold the book they are reading in generally inclined to one ſide, in order to attain a greater degree of illumination. As they can only ſee diſtinctly objects that are near, they are obliged, by a ſtrong effort of the mind, to cauſe the axes of the eyes to converge; this effort being painful, forces them often to turn away one of their eyes, which producing double viſion, they are obliged to ſhut it. When they hold a book directly before their eyes, the picture will fall upon the middle of the retina; but if they hold it obliquely, it will fall upon the ſide of the retina; now the middle of the retina is further from the fore part of the eye than the ſide of it is. Therefore though the picture be ſo near to the fore part of the eye as to be confuſed if it fall upon the middle, it may be diſtinct when it falls upon the ſide.

As thoſe who are very ſhort-ſighted do not perceive the motion of the eyes and features, they ſeldom look attentively at thoſe with whom they are converſing: it is from this circumſtance that Pliny terms the prominent-eyed *hebetiores*; not that this defect in ſight impairs genius, or leſſens the powers of the mind; but as it deprives them of the rapid communications that are made by the eye, it apparently leſſens that vivacity of conception, which always accompanies a vigorous mind.

Happily for the ſhort-ſighted, the principal inconveniences of their ſight may be remedied by the uſe of concave glaſſes; by their aſſiſtance, thoſe whoſe ſphere of diſtinct viſion ſcarce extended beyond their arm, are enabled to diſtinguiſh, very ſatisfactorily, objects at a conſiderable diſtance; the concave lens produces diſtinct viſion, by cauſing the rays to diverge more, and unite at the retina, inſtead of meeting before they reach the bottom of the eye.

In the choice of glaſſes for the ſhort-ſighted, no rules can be laid down; it is a defect that has no connection with age, no ſtated progreſſion that can be a foundation to guide the optician, or lead him to recommend one glaſs in preference to another; the whole muſt depend on the obſervation of the ſhort-ſighted themſelves, who, by trying glaſſes of different degrees of concavity, will ſoon find out that whoſe effects are moſt advantageous, producing diſtinct viſion at different diſtances.

If the ſhort-ſighted perſon is ſo far removed from an optician, as not to have an opportunity of trying a variety of lenſes, he may be nearly ſuited, by ſending to him the greateſt diſtance at which, with his naked eye, he can ſee diſtinctly; he will, by the following rule, be enabled to ſuit him with tolerable exactneſs.

Multiply the diſtance at which the ſhort-ſighted perſon ſees diſtinctly with his naked eye, by the diſtance at which it is required he ſhould ſee diſtinctly by a concave glaſs, and divide the product by the difference between the aforeſaid diſtances: if the required diſtance be very remote, the glaſſes muſt be of that radius at which they ſee diſtinctly with their naked eyes.

The benefit the ſhort-ſighted receive from concave glaſſes, is not ſo great as the long-ſighted find by a convex lens; for an object is not only magnified, but the eye receives alſo a larger pencil of light from each viſible point, becauſe the rays enter leſs diverging: whereas the concave not only diminiſhes the object in ſize, but it leſſens alſo the quantity of light, as it renders the rays more diverging; conſequently the ſhort-ſighted do not ſee remote objects, unleſs they are very large and bright, ſo well through a concave lens as theory promiſes: for the chief impediment to a diſtinct view of remote objects, is their want of light and magnitude, but both of theſe a concave lens increaſes.

It is generally ſuppoſed, that the ſhort-ſighted become leſs ſo as they advance in years, as the natural ſhrinking and decay in the humours of the eye leſſen it's convexity, and thus adapt it better for viewing of diſtant objects; but among the great number of ſhort-ſighted that I have accommodated with glaſſes, I have ever found the reverſe of this theory to be true, and the eyes of the myopes never required glaſſes leſs concave, but generally more concave as they grew older, to enable them to ſee at the ſame diſtance.

Further, the effects of habit, which are in moſt caſes very powerful, but peculiarly ſo in the affections of the eye, have a natural tendency to increaſe the defect of the myopes; for by frequently looking cloſe to objects, in order to ſee them diſtinctly, they would make themſelves near-ſighted, though their eyes were naturally the reverſe: hence we find, that watch-makers, engravers, and ſtudious perſons, often bring on this defect. By reading or working at as great a diſtance as poſſible, and often looking at remote objects, the degree of ſhort-ſightedneſs may be much leſſened. As children in general read much nearer than grown perſons, if they are ſuffered to indulge this propenſity, they become naturally ſhort-ſighted.

I have found it neceſſary, in ſome inſtances, to give convex glaſſes to the ſhort-ſighted, when very far advanced in age, not becauſe their eyes were grown leſs convex, but to give them more light, and counteract an extreme contraction of the pupil.

Great as are the diſadvantages of the ſhort-ſighted, they are leſs, perhaps, with reſpect to diſtant objects, than is generally imagined; they ſee the brighter ſtars and planets, nearly as well as other people. They are prevented indeed from diſtinguiſhing beyond a certain ſmall diſtance, the ſmall parts of an object which are very viſible to another; thus they cannot diſtinguiſh the features of a face acroſs a room, and as objects are generally diſcriminated by their minuter parts, their diſadvantage in viewing objects at a moderate diſtance is very evident. But though ſuch a perſon cannot diſcern the minutiæ of objects, unleſs they are very large and very near him; yet he can perceive any object in the groſs, at a conſiderable diſtance, if it be not too ſmall: thus he may perceive a man at the diſtance of ſeveral paces, but muſt advance within one or two, before he can determine who he is, or call him by his name; he will ſee a large tree much further, and from experience in ſuch caſes, will perceive, that a large obſcure object at a great diſtance is an houſe, to the ſurprize of his friends who are acquainted with the nature of his ſight. On theſe principles, we may eaſily account for the apparent paradox of the pur-blind, or thoſe who can ſcarcely ſee a ſmall object at arm's length, yet diſcovering thoſe that are very remote.

LECTURE XVIII.

ON THE

NATURE OF VISION.

OF THE DISTANCE, MAGNITUDE, AND APPARENT PLACE OF OBJECTS.

LET us now conſider by what means the *mind*, aſſiſted by the eyes, is informed of the *diſtance* of objects. *Diſtance*, of itſelf and immediately, is *imperceptible*; for it is only a line directed endways to the eye. Thus, if I look endways at this piece of packthread, the length of it would be inviſible from it's ſituation, and therefore the image on the retina can only be a *point*, which point will be invariably the ſame at all diſtances; whether the object be a thouſand miles, or only a foot from us, the point is ſtill the ſame.

The change of conformation in the eye, is the firſt means whereby the eye judges of diſtance. If the figure of the eye and the ſituation of all it's parts were to continue always the ſame at all diſtances of the objects we are looking at, the picture of ſome objects upon the retina would be confuſed, becauſe they are too far off, and others becauſe they are too near. In viewing objects at ſmall but different diſtances, the eye muſt change it's conformation for procuring diſtinct viſion. Young people have commonly the power of adapting their eyes to all diſtances of the object, from 6 or 7 inches to 15 or 16 feet, ſo as to have perfect and diſtinct viſion at any diſtance within theſe limits.

The effort they uſe to adapt the eye to any particular diſtance of objects, within that diſtance, will become a ſign of that diſtance.

This change in the conformation of the eye has it's limits, beyond which it cannot go; it can therefore be of no uſe to us in judging of the diſtance of objects that are placed beyond the limits of diſtinct viſion. But as the object appears more or leſs confuſed, acccording as it is more or leſs removed from theſe diſtances, the degree of confuſion in the objects aſſiſts the mind in judging of diſtances, and becomes a ſign thereof conſiderably beyond the limits of diſtinct viſion. This confuſedneſs has alſo it's bounds, beyond which the image on the retina will not be ſenſibly more indiſtinct, though the object be removed to a much greater diſtance.

If therefore we had no other means but this of perceiving the diſtance of viſible objects, the moſt diſtant would not appear to be above 20 or 30 feet from the eye; and the tops of houſes and trees would ſeem to touch the clouds, becauſe in that caſe the ſigns of all greater diſtances being the ſame; they have the ſame ſignification, and give the ſame perception of diſtance.

We are therefore provided with another means, namely, *the inclination of the optic axes*. In viewing an object attentively with both eyes, we always direct both eyes towards it, and the nearer the object is the more they will be inclined to each other, and the more remote the leſs will be this inclination: and although we are not conſcious of this inclination, yet we are conſcious of the effort employed in it. By this means we perceive ſmall diſtances more accurately than we could do by the conformation of the eye only; and therefore we find that thoſe who have loſt the ſight of one eye, are apt, even within arm's length, to make miſtakes in the diſtance of objects, which are eaſily avoided by thoſe who ſee with both eyes: ſuch miſtakes are often diſcovered in ſnuffing a candle, threading a needle, and filling a tea-cup. A perſon who plays well at tennis, will find himſelf ſubject to the ſame miſtakes the firſt time he plays with his eye hoodwinked.

To be convinced of the truth of this obſervation, ſuſpend by a thread a ring, ſo that the edge may be towards you, and it's hole look right and left; take a ſtick which is crooked at the end, and retiring 2 or 3 paces from the ring, cover one eye with your hand, and endeavour with the other to paſs the crooked end of the rod through the ring: eaſy as the experiment may appear, you will ſcarcely ſucceed once in a hundred times if you move the rod quickly.

Although this ſecond mean of perceiving the diſtance of viſible objects be more exact and determinate than the firſt, yet it hath it's limits, beyond which it can be of no uſe. For when the optic axes directed to an object are ſo nearly parallel, that in directing them to an object yet more diſtant, we are not conſcious of any new effort, nor have any different ſenſation, our perception of diſtance ſtops; and as all more diſtant objects affect the eye in the ſame manner, we perceive them to be at the ſame diſtance. This ſhews why the ſun, moon, planets, and fixed ſtars, when not ſeen near the horizon, appear to be all at the ſame diſtance, as if they touched the concave ſurface of a great ſphere.

The colours and degrees of brightneſs in objects is a cauſe of a difference of apparent diſtance. As objects become more and more remote, they gradualy appear more faint, languid, and obſcure; their minute parts become more indiſtinct; their outline leſs accurately defined; their colours not only loſe their luſtre, but degenerate from their natural hue, and are tinged with the azure of the intervening atmoſphere. It is by theſe means that painters can repreſent upon the ſame canvas objects at very different diſtances. The diminution of magnitude in an object would not be ſufficient to make it appear at a great diſtance without this degradation of colour, indiſtinctneſs of the outline, and of the minute parts. If a painter ſhould make a human figure, ten times leſs than other human figures that are in the ſame piece, having the colours as bright, and the outline and minute parts as accurately defined, it would not have the appearance of a man at a great diſtance, but of a pigmy or Lilliputian. Painters therefore, to give their figures a due degree of remoteneſs, are obliged to lay over each a thick colouring of air; for the more remote the object, the more do it's own colours ſeem loſt in that of the intervening atmoſphere. This is called *keeping*, for by this means every object in a picture ſeems to keep it's proper diſtance from the reſt.

Dr. Smith gives us a curious obſervation made by Biſhop Berkeley in his travels through Italy and Sicily. He obſerved, that in thoſe countries, cities and palaces, ſeen at a great diſtance, appeared nearer to him by ſeveral miles than they really were; and this he attributed to the purity of the Italian and Sicilian air, which gave to very diſtant objects that degree of brightneſs and diſtinctneſs, which in the groſſer air of England was only ſeen in thoſe that were near. Hence a chamber appears leſs when it's walls are whitened, and fields and hills appear leſs when covered with ſnow.

It is alſo certain, that in air uncommonly pure we are apt to think viſible objects nearer and leſs than they really are, and in air uncommonly foggy we are apt to think them more diſtant and larger than the truth. A weſterly proſpect in a clear morning, with the ſun upon it, appears nearer than when the ſun is higher up and more weſterly. The diſpoſition of the clouds and innumerable other circumſtances affect the brightneſs of objects, and contribute their ſhare in forming our ideas of the diſtance of remote objects.

The length of the ground-plane, or number of intervening parts perceived in it, is another mean by which we perceive diſtance. We are ſo much accuſtomed to meaſure with our eye the ground we travel over, and to compare the judgment of diſtances formed by ſight with actual experience or information, that we by degrees in this way form a more accurate judgment of the diſtance of terreſtrial objects than we could do by any of the above-mentioned means.

A given extent appears longer according as it contains a greater number of viſible parts; and hence two remote and very unequal diſtances may appear very unequal, according to the different circumſtances of the intervening parts, and as the ſpectator is differently elevated. Thus a hedge having in it ſeveral grown trees, generally looks longer than a clipt hedge, or the ſame extent of ground in an open field. For the ſame reaſon a row of houſes, columns, or trees regularly planted, appear longer than a plain wall of the ſame extent; for in this caſe there are not only more viſible and remarkable parts in the one caſe, but our pre-knowledge of the ſeveral intervening objects being equidiſtant, tends to protract the apparent length of the whole chain ſtill longer. A river at firſt does not look ſo broad as it does after you have had a ſide view of the bridge acroſs; and indeed a given extent of water does not appear ſo long as the ſame extent of land, it being more difficult to diſtinguiſh parts in the ſurface of the one, than it is in the ſurface of the other. Hence a perſon unuſed to a ſea proſpect will be much miſtaken in his judgment of diſtances; a ſhip that is 8 or 10 miles from the ſhore, will ſcarce ſeem to him to be a mile off.

When part of the intervening chain is inviſible, or obſcurely ſeen, the apparent diſtances of objects that are beyond that part will be accordingly leſs. Thus a certain extent of rough, uneven ground, appears ſhorter than the ſame extent of plain ground; the prominent parts hiding the cavities behind them, the apparent diſtance is ſo much the leſs by the loſs of thoſe inviſible parts. For the ſame reaſon the brow of an hill ſeen over the top of another frequently looks nearer than it does after the vale between preſents itſelf to our view; and the banks of a river at ſome diſtance, will ſeem contiguous, if no part of the ſurface of the river is viſible.

The known diſtance of the terreſtrial objects which terminate our view, makes that part of the ſky which is towards the horizon appear more diſtant than that which is towards the zenith. And hence the apparent figure of the ſky is not that of a hemiſphere, but rather a leſs ſegment of a ſphere; and the diameter of the ſun or moon, and the diſtance between two fixed ſtars, ſeen contiguous to a hill, or to any terreſtrial object, appear much greater than when no ſuch object ſtrikes the eye at the ſame time.

When the viſible horizon is terminated by very diſtant objects, the celeſtial vault is enlarged in all it's dimenſions. When viewed from a confined ſtreet or lane, it bears ſome proportion to the buildings which ſurround it; but when viewed from a large plain, terminated on all ſides by hills riſing one above another to the diſtance of 20 or more miles from the eye, you ſee as it were another heaven, whoſe magnificence declares the greatneſs of it's AUTHOR, and puts every human edifice out of countenance; for the lofty ſpires and gorgeous palaces ſhrink into nothing before it, and bear no more proportion to the celeſtial dome, than their maker to it's MAKER.

Different degrees of apparent diſtances are ſuggeſted by the diminution of their apparent or viſible magnitude. We know, by experience, what figure a man or any known object makes to our eyes at ten feet, and we perceive a gradual diminution of the viſible figure at 20, 40, 100 feet, and ſo on till it at laſt vaniſhes: hence a certain viſible magnitude of a known object becomes the ſign of a certain determinate diſtance, and carries with it the conception and belief of that diſtance.

But when we are ignorant of the real magnitude of an object, we can never from the apparent magnitude form any judgment of it's diſtance. Hence we are ſo frequently deceived in our eſtimate of diſtance, by the extraordinary magnitude of any object ſeen at the end of it; as, in travelling towards a large city, or a caſtle, or a cathedral church, or a large mountain, we imagine them nearer than we find them to be. This is alſo the reaſon why animals and all ſmall objects, ſeen in vallies, contiguous to large mountains, appear exceedingly ſmall; for we think the mountain nearer to us than if it were ſmaller, and we ſhould be ſurpriſed at the apparent ſmallneſs of the neighbouring animals, if we thought them farther off. Hence alſo objects appear ſmaller to the eye when ſeen from a high building, than they ſeem to be when viewed from the ſame diſtance on level ground.

Let a boy, who has never been upon any high building, go to the top of the Monument, and look down into the ſtreet, and the objects ſeen there will appear to him ſo ſmall as to occaſion much ſurpriſe. But 10 or 20 years after, if he has now and then uſed himſelf to look from that and other great heights, the object will not appear ſo ſmall. For this reaſon ſtatues placed upon very high buildings ought to be made of a larger ſize than thoſe which are ſeen at a nearer diſtance.

OF APPARENT MAGNITUDE.

The apparent magnitude of very diſtant objects is neither determined by the angle under which they are ſeen, nor in the exact proportion of that angle compared with their true diſtance, but is compounded with a deception concerning that diſtance, inſomuch that, if we had no idea of the difference in the diſtance of objects, each would appear in magnitude proportional to the angle under which it is ſeen; and if our apprehenſion of the diſtance was always juſt, our ideas of their magnitude would be in all diſtances unvaried; but in proportion as we err in our conception of diſtance, the greater angle ſuggeſts a greater magnitude. It is probable, *that the apparent magnitudes are either exactly or very nearly in the compound ratio of the viſual angles and apparent diſtances.*

We are as frequently deceived in our notions of magnitude as thoſe of diſtance. A fly ſkipping before an unattentive ſpectator, will ſometimes excite the idea of a crow flying afar off; but as ſoon as the miſtake in the diſtance is found, the crow will dwindle into a fly. Thus alſo, as we have obſerved in foggy weather and in the duſk, objects appear further off than they really are, and in theſe caſes proportionably larger, as there is a greater miſtake in the diſtance. Thus a ſmall heap of ſtones has been miſtaken for the ruins of a large building, &c.

The diminution of apparent magnitude is ſo very ſmall in proportion to the greater increaſe of diſtance, that in general the viſual angles ſubtended by objects can have but little ſhare in forming our judgment of their diſtances; and indeed if the caſe was otherwiſe, it would be almoſt impoſſible for us to gueſs aright, either as to diſtance or magnitude. For inſtance, if we did not judge independently of the viſual angle, how could we know a child from a grown perſon, or even a pin from a May-pole. For the largeſt object being removed to a greater diſtance may ſubtend an angle leſs than any aſſignable one; as objects generally appear nearer when the intervening chain is not perceived: and the ſame reaſon operates, as already obſerved, in making them appear proportionably ſmaller. Thus the diſtance of an object joined with it's viſible magnitude, is a ſign of it's real magnitude; and the diſtance of the ſeveral parts of an object joined with it's viſible figure, becomes a ſign of it's real figure.

When you look at a globe ſtanding before you, by the original powers of ſight you perceive only ſomething of a circular form, variouſly coloured. The *viſible figure* hath no diſtance from the eye, no convexity, nor hath it three dimenſions; even it's length and breadth are incapable of being meaſured by inches, feet, or other linear meaſures. But when you have learned to perceive the diſtance of every part of this object from the eye, this perception gives it convexity, and a ſpherical figure; and adds a third dimenſion to that which had but two before. The diſtance of the whole object enables you alſo to perceive how an inch or a foot of length affects the eye at that diſtance: you perceive by your eye the dimenſions of the globe.

So numerous are the relations between the eye and the underſtanding, between light and knowledge, that there are very few parts of optics from which you may not deduce ſome practical advantages. Thus the judgment of the mind correſponds with the ſtrength and colour of the objects whereon they are paſſed: but the further objects are removed, they grow more faint and indiſtinct, and of courſe our opinions concerning them will be leſs vivid and clear. Both pleaſures and pains at a diſtance appear ſcarce worth our regarding, or giving ourſelves any trouble about them; the preſent occupies our thoughts, and forcibly carries away the preference in our imagination from the future, againſt the cleareſt and ſureſt deciſions of our underſtanding. To rectify this imperfection of our nature, is worthy of your utmoſt application; and you may eaſily do it by *gradually* inuring the mental eye to diſcern objects at a diſtance. It is the quickneſs of this *moral ſenſe*, or an habitual full perſuaſion of certain good and evil, however remote, being equally valuable with the preſent, that conſtitutes the virtue of prudence.

OF APPARENT MOTION.

If two objects at different diſtances from the eye move in parallel lines, nearly at right angles to the optic axis, and with the ſame velocity, the moſt diſtant will appear to move ſloweſt, and the neareſt will appear to move quickeſt, becauſe the ſpace deſcribed by the moſt diſtant object will ſubtend a much ſmaller angle to the eye.

If the directions in which the bodies move are not parallel, the *neareſt* object may appear to move ſlower than the more *diſtant*, although it really moves quicker, if the ſpace deſcribed be ſituated ſo obliquely to the viſual rays, that they form at the eye much ſmaller angles, than ſmaller ſpaces deſcribed by the more diſtant object, which is expoſed more directly to the eye.

If two objects unequally diſtant from the eye move with unequal velocities in the ſame direction, their apparent velocities are in a ratio compounded of the direct ratio of their true velocities, and the reciprocal one of their diſtances from the eye.

As objects in motion will have different apparent velocities at different diſtances; ſo to a ſpectator in motion, objects at reſt will have different apparent velocities. Thus a paſſenger in a coach ſees the trees in the next hedge move ſwiftly backwards, while thoſe in the field beyond move ſlower, and thoſe beyond theſe ſtill ſlower, and ſo on, thoſe that are very remote being ſcarce perceived to move at all. And if a ſpectator in motion keeps his eye fixed upon an object at ſome diſtance, objects that are pretty near to it will appear at reſt, whilſt nearer objects will appear to go backwards, and more remote ones progreſſively forward, the ſame way as the ſpectator.

If two or more objects having the ſame apparent velocity move all the ſame way, an object at reſt, by which they paſs, may appear to move the contrary way, while the objects in motion may appear at reſt: for as their images keep the ſame diſtance upon the retina, no motion among them can be perceived. If the ſpectator inſenſibly moves his eye, ſo as to keep theſe images in the ſame place, the image of the object at reſt will paſs ſucceſſively over them, in the ſame manner as if that object had been in motion the contrary way. The ſame phenomenon may happen, if the ſingle object be in motion, either the ſame or the contrary way; only it's apparent motion will be quicker or ſlower, direct or retrograde, according to different circumſtances. Thus when the clouds move ſucceſſively over the moon, ſhe ſeems to go with their velocity the contrary way, whether that be eaſtward or weſtward.

From hence you may ſee how difficult it is to form a juſt eſtimate of the real velocities of objects from apparent ones, ſince we ought to know both the directions and diſtances of the moving objects, neither of which in many caſes can be gueſſed at with tolerable accuracy.

Bodies in motion muſt move with a certain degree of velocity in order to become perceptible. Though it is difficult to aſſign with accuracy the ſpace that muſt be paſſed over in a given time, in order to be ſenſible; yet in general we may ſay that it ſhould deſcribe, in a ſecond of time, a ſpace that will form at the eye an angle of 15 or 20 ſeconds of a degree. Hence we ſee why the heavenly bodies are not perceived to move, the ſpaces deſcribed by them in a minute not ſubtending an angle of above ¼ degree, when their apparent motion is greateſt. For the ſame reaſon we do not perceive the motion of the hour, or even the minute hand of a watch. In the ſame manner a prodigious great velocity, as the diurnal motion of the heavenly bodies, may be yet too ſlow to be perceived; and an object may move with ſo great a velocity as not to be perceived, as the flight of a ball out of a gun.

An object moving with great velocity is not ſeen unleſs it be very luminous. Thus a cannon ball is not ſeen, if it be viewed tranſverely; but if it be viewed according to the line it deſcribes, it may be ſeen, becauſe it's picture continues long on the ſame place of the retina, and therefore receives a ſtronger impreſſion.

As we have all been children before we were men, we have all, I doubt not, at that ſeaſon amuſed ourſelves with many childiſh diverſions, one of which you may remember was burning a ſmall ſtick to a live coal, and whiſking it round to make gold lace, as we called it. We little thought then of making experiments in philoſophy; but we may turn this innocent amuſement to that uſe, in our riper years, by gathering from thence, that our organs can continue ſenſation after the impulſe of objects exciting it is over: for the coal is in one point only at one time, and can be ſeen only where it is; yet there appears an entire circle of fire, which could not happen unleſs the light coming from it, at every point, put the optic nerves into a motion that laſted until the object returned to the ſame point again; nor, unleſs this motion raiſed the ſame perception in the mind as it did upon the firſt ſtriking of the light. For if the ſtick be not twirled ſwiftly enough, ſo that it cannot make a ſecond impreſſion from the ſame point, before the motion excited by the firſt be over, you will not ſee a whole fiery ring, but a lucid ſpot paſſing ſucceſſively through every part of the circle.

On the principles we have laid down, are explained what are called *fallacies in viſion.* They depend principally on our miſtaking the diſtances of objects. Thus, parallel lines, as long viſtas, conſiſting of parallel rows of trees, ſeem to converge more and more as they are farther extended from the eye; becauſe the lines which meaſure their intervals, and which are always equal, ſubtend ſmaller angles, the more remote they are, and ſo appear perpetually diminiſhing, while we, at the ſame time, miſtake the diſtance. For the ſame reaſon, the remote parts of a horizontal walk, or a long floor, will appear to aſcend gradually; and the more remote the objects are that are placed upon it, the higher they will appear, till the laſt be ſeen on a level with the eye: whereas the ceiling of a long gallery appears to deſcend towards a horizontal line, drawn from the eye to a ſpectator. And the ſurface of the *ſea*, ſeen from an eminence, ſeems to riſe higher and higher, the farther we look: and the upward parts of high buildings incline forwards over the parts below; ſo that ſtatues on the top of ſuch buildings, in order to appear upright, muſt recline or bend backwards.

There is another phenomenon, however, not ſo eaſily accounted for: if a perſon turns ſwiftly round, without changing his place, all objects about will ſeem to move round in a contrary way; and this deception continues not only while the perſon himſelf moves round, but which is more ſurpriſing, it continues alſo for ſome time after he ceaſes to move; *i. e.* when both the eye and the object are at reſt. The firſt is not ſo difficult to explain, for the motion of the object on the retina eaſily explains it: but why it continues when both the eye and the object are at reſt, has not yet been well underſtood. It appears to me, that the ſeat of ſenſe is not altogether paſſive in receiving images, but poſitively directs a ray from itſelf to every object it perceives; the action and reaction between objects and the ſeat of ſenſe, is wholly reciprocal. Hence we ſee objects, or their image, after the eye is turned from them. Hence, alſo, in a delirium, the objects of the imagination receive a real repreſentation in the organs of ſenſe: and hence we do not ſee an object the eye happens to be fixed on, if the attention be otherwiſe engaged.

It is, however, to be obſerved, with reſpect to what we call the *fallacies in viſion*, the appearance of things to the eye always correſponds to the fixed laws of nature; therefore, to ſpeak properly, there is no fallacy in the ſenſes. Nature always ſpeaks the ſame language, and uſes the ſame ſigns, in the ſame circumſtances: but we ſometimes miſtake the meaning of the ſigns, either through ignorance of the laws of nature, or through ignorance of the circumſtances which attend the ſigns.

To a man unacquainted with the principle of optics, almoſt every experiment that is made with the priſm, with the magic lanthorn, with the teleſcope and the microſcope, ſeem to produce ſome fallacy in viſion. Even the appearance of a common mirror, to one altogether unacquainted with the effects of it, would ſeem moſt remarkably fallacious: for how can a man be more impoſed upon, than in ſeeing that before him which is really behind him? How can he be more impoſed upon, than in being made to ſee himſelf ſeveral yards removed from himſelf? Yet children, even before they can ſpeak their mother-tongue, learn not to be deceived by theſe appearances. Theſe, as well as all other ſurprizing appearances produced by optical glaſſes, are a part of the viſual language; and to thoſe who underſtand the laws of nature concerning light and colours, are in no wiſe fallacious, but have a diſtinct and true meaning.

OF VISION BY IMAGES.

The particular phenomena of viſion, in given caſes, by reflected and refracted light, have been the principal ſubject of the preceding optical Lectures: but, on account of their univerſality, it will be proper to make a few more obſervations on this ſubject.

Viſion of real objects ſeen directly, and viſion by images, are both founded on the ſame principles: that is, ſimilar impreſſions, or the ſame kind of images upon the retina, excite ſimilar ideas in both caſes. Conſequently, *objects*, when ſeen by reflected or refracted rays, are ſeen in the places of *their laſt images*. If theſe images are at moderate diſtances before the eye, the ſeveral circumſtances by which we form the ideas of the apparent diſtances of objects ſeen by naked viſion, are alſo taken into the account. Univerſally, every viſible point of an object appears ſomewhere in the direction of the axis of the pencil of rays proceeding from it to the eye after it's laſt reflection or refraction.

In viſion by images, we are generally deprived of many circumſtances by which we uſually judge of diſtances; and this makes it difficult, in moſt caſes, to determine the place of an image, particularly if it be further off than two or three yards. Theſe difficulties are frequently increaſed by ſome peculiarities appertaining to the images which we are not accuſtomed to, and for which we are at a loſs to make the proper allowances. But when the image is within the above-mentioned limits, we can, in moſt caſes, determine it's place with ſufficient accuracy: and here, as well as in naked viſion, the nearer we can determine the place from whence the rays converge to the eye, the more diſtinct will the image appear.

The apparent magnitudes of objects, ſeen by reflection or refraction, are either accurately, or very nearly, *as the rectangles under the viſual angles and apparent diſtances of their laſt images.* In all caſes, the apparent place, poſition, and figure of an object ſeen by refracted or reflected light, are as thoſe of it's laſt image. For the rays proceeding from the image to the eye, form a ſucceſſion of phyſical points after the ſame manner as if they came from a real object, and therefore excite an idea of an object equal and ſimilar to the image.

Hence, as you have ſeen, in viſion by images, we are liable to many deceptions, ſome of which are entertaining, as well as ſurpriſing; for not only the place of an image, but very often it's poſition, magnitude, and even figure, ſhall be quite different from the real object.

OF VISION BY IMAGES.*

As this is a ſubject of the greateſt importance in optics, it will be worth while to conſider it when ſtated in different words, with ſome additional circumſtances.

When the rays in a pencil diverge from a point, and either by reflection or refraction are brought all together again, they then form a luminous point correſponding to that from which they diverged.

By this means a new *viſible* object is formed, called the image of the other; for the eye now receives the rays as coming from this latter point, and therefore judges the former point to be in the place of the latter; and as this is true for every point of any object, every object may thus actually be formed a-new, ſo far as regards our *viſible* ideas. And the rays diverging to the eye from the image thus formed, in the ſame manner as if they came directly from the object, excite an idea of that image, or of an object ſimilar to it.

Now, if the pencils of rays, which diverge from all points of an object, be again reſpectively collected at the ſame diſtances, they then form a new viſible object equal to that from whence they

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* Viner's Plan of a Courſe of Lectures, p. 87.

they flowed : but if the points of this new object, called the image, correſponding to thoſe of the original object, be at a greater or leſs diſtance, they form a new *viſible* object greater or leſs than the *original* one. Thus, therefore, we are able to form a new *viſible* object, very near to us, exactly ſimilar to an object at a great diſtance. I call this a *viſible* object, becauſe at the place where it is formed there is nothing to excite correſponding *tangible* ideas, as in the object from whence the rays firſt flowed. But in reſpect to our viſible ideas, which we are here only conſidering, it is as much an object as the other; the eye may, therefore, be ſo ſituated, in reſpect to this new object, that it may appear much nearer than the original object; every object appearing greater, the nearer it is to the eye.

Now, with reſpect to the *brightneſs* of this new viſible object, we are to conſider that when the eye looks directly at any object, it receives no more rays from any one point, than what can directly enter the pupil: but, when an image is formed by a lens, for inſtance, all the rays from any one point of the object which falls upon the lens are collected together, and form a point of the image. Now if the diameter of the pupil of the eye =0.1 inch, and the diameter of the lens be 5 inches, their areas will be as 0.01 to 25; or, as 1. to 2500: there are, therefore, *cæteris paribus*, 2500 times as many rays collected to form every point of the image by the lens, as enter the eye, and form the image, ſuppoſing all the rays to be refracted. Now, although the rays diverge from every point of this image, formed by the lens, and therefore where the eye is ſituated it may not receive them all, yet, being ſituated near to it, it will receive a very conſiderable part, and more in proportion as it is nearer.

Hence the number of rays which the eye receives from any point of this image, may be greater than that which it receives directly from the object; and thus the image may be brighter than the object. Theſe are ſome of the reaſons why any diſtant object may be made to appear larger and brighter: and the common expreſſion, that the object is brought nearer, is not incorrect; for the viſible object is actually nearer, but not being accompanied with any tangible ideas, we call it an image of the other; whereas it is a viſible object formed by the ſame rays as the original viſible object. Looking, therefore, at the viſible object thus formed, we get an idea of the original viſible object, ſeen under the ſame angle; and from thence, by aſſociation, we conclude, what are the correſponding tangible ideas.

I ſhall conclude this Lecture on viſion, with ſome more reflections on the eye. They are extracted from a ſermon of Mr. Newlin's.

Light is truly pleaſing in it's own natural ſimplicity, and is the ornament and glory of every other object. But the eye receives it always with a freſh and increaſing pleaſure, as it is varied and diverſified, by putting on ſo many ſorts of colours, like ſo many changes of raiment.

Every time that the eye opens and expands itſelf, it draws as it were the whole viſible world into it's own narrow compaſs; and there is a new creation within itſelf. *The ſun, that marvellous inſtrument of the Moſt High; the moon, that ſhineth in the firmament of heaven; the ſtars, that numberleſs hoſt; the rainbow, that glorious circle, which is bent by the hands of the Moſt High;* the virgin purity and unſullied whiteneſs of the ſnow; the beautiful embroidery of flowers; the rich cloathing of the meadows, *and the cattle upon a thouſand hills,* are preſented to the eye by the LORD OUR

MAKER, and ſet before it, as on a ſpacious theatre.

The great ſource of light, which ſhews every thing to the eye, caſts forth ſo bright and dazzling a luſtre, that it would bear too hard upon it, and injure our viſual faculty, if it were placed too near the ſight; but it is fixed at ſo remote a diſtance from us, that we look upon it with pleaſure, and enjoy it's glory.

When the eye is wearied with it's daily ſervice, and the night ſpreads a veil of darkneſs over this lower world, the curtain that is hung before the eye falls down, and the eye-lids are ſhut with a cloſe ſeal, till we have renewed our ſtrength, and the morning reſtores the world to our view: the eye-lid not only affording refreſhment and eaſe to the eye, but defending it from the ſecret perils and inviſible dangers of the night.

And when day breaks, it does not ſhine forth at once, in full perfection, but gradually manifeſts itſelf, that the eye may not be overpowered, by a ſudden iſſuing out, and too mighty a ſtream of light. The ſun ſends a harbinger before him, to give notice of his appearance, that the dawning of the day may prepare us to receive him.

Though every colour has a peculiar beauty, yet they are not all equally agreeable and refreſhing to the eye: but the verdure of the fields is moſt particularly pleaſing to it, and we can bear to dwell the longeſt upon it: GOD has appointed it for the common dreſs of nature, and made this colour the moſt familiar to our ſight. *He leads us through the green paſtures*, and adorns the herbs and plants with many varieties, even in the ſame colour, and changes it every day.

Time would fail me even in attempting to deſcribe all the pleaſures and advantages of ſight. I cannot, however, leave the ſubject without one or two obſervations. The eyes are a faithful guard to the whole man, and are placed as in a friendly watch-tower, to diſcern his danger, and give him friendly warning, while it is yet afar off.

The eye is inſtrumental in promoting the happineſs of converſation. It is the eye that meets our friend with joy, and kindles and imparts the heavenly flame of friendſhip. It is the eye that pities, and ſpares, and yearns over the miſerable object, with generous compaſſion. It was with the *eye* that our SAVIOUR reproved St. Peter. *O Lord, how marvellous are thy works! in wiſdom haſt thou made them all!* The eye that sees, gives witneſs of thee; and the ear that hears, confirms it's teſtimony.

LECTURE XIX.

OF COLOURS.

NO philoſophical ſubject is more worthy of your attention than *light*; it is the means by which all the beauties and glories of the creation are laid open to view; with ſome of it's curious properties you are well acquainted; a new ſcene will now riſe before you equally admirable with thoſe that have preceded.

I have hitherto conſidered light as a body uncompounded, and of parts reſembling each other; but we are going to examine it's texture more cloſely. You will now ſee that this fluid, ſo ſimple in appearance, is made up of very different particles; that it is compoſed of very different coloured tints; and that from the nature of this compoſition ariſes that charming variety of ſhades which paints the face of nature.

Whatever pleaſures we derive from the beauty of colouring, we owe it to the different rays of light, each object ſending back to our eyes thoſe rays, which *it's ſurface* is beſt adapted to reflect: in this ſenſe the bluſhing beauties of the roſe, and the modeſt blue of the violet, may be conſidered as not in the objects themſelves, but in the light that adorns them. Odour, ſoftneſs, and beauty of figure, are their own; but it is light which dreſſes them up in thoſe robes which ſhame the monarch's glory.

Natural philoſophers were formerly of opinion, that the ſolar light was ſimple and uniform, without any difference or variety in it's parts, and that the different colours of objects were made by refraction, reflection, or ſhadows. But *Newton* taught them the errors of their former opinions; he ſhewed them to diſſect a ſingle ray of light with the minuteſt preciſion, and demonſtrated that every ray was itſelf a compoſition of ſeveral rays all of different colours, each of which when ſeparate held to it's own nature, ſimple and unchanged by every experiment that could be tried upon it. Or to be more particular, light is not all ſimilar and homogenial, but compounded of heterogenial and diſſimilar rays, ſome of which in like inſtances being more refrangible, and others leſs refrangible, and thoſe which are moſt refrangible are alſo moſt reflexible; and according as they differ in refrangibility and reflexibility, they are endowed with the power of exciting in us ſenſations of different colours.

Newton's theory of light and colours is ſtriking and beautiful in itſelf, and deduced from clear and deciſive experiments, and may be almoſt ſaid to demonſtrate clearly, 1ſt, That lights which differ in colour, differ alſo in degrees of refrangibility.

2d, That the light of the ſun, notwithſtanding it's uniform appearance, conſiſts of rays differently refrangible.

3d, That thoſe rays which are more refrangible than others, are alſo more reflexible.

4th, That as the rays of light differ in degrees of refrangibility and reflexibility, ſo they alſo differ in their diſpoſition to exhibit this or that particular colour; and that colours are not qualifications of light derived from refractions or reflections of natural bodies, as was generally believed, but original and connate properties, which are different in different rays, ſome rays being diſpoſed to exhibit a red colour and no other, and ſome a green and no other, and ſo of the reſt of the priſmatic colours.

5th, That the light of the ſun conſiſts of *violet* making, *indigo* making, *blue* making, *green* making, *yellow* making, *orange* making, and *red* making rays, and all of theſe are different in their degrees of refrangibility and reflexibility; for the rays which produce red colours are the leaſt refrangible, and thoſe that make the violet the moſt; and the reſt are more or leſs refrangible as they approach either of theſe extremes, in the order already mentioned: that is, orange is leaſt refrangible next to red, yellow next to orange, and ſo on; ſo that to the ſame degree of refrangibility there ever belongs the ſame colour, and to the ſame colour the ſame degree of refrangibility.

6th, Every homogenial ray, conſidered apart, is refracted according to one and the ſame rule, ſo that it's ſine of incidence is to it's ſine of refraction in a given ratio; that is, every different coloured ray has a different ratio belonging to it.

7th, The ſpecies of colour, and degree of refrangibility and reflexibility, proper to any particular ſort of rays, is not mutable by reflection or refraction from natural bodies, nor by any other cauſe that has been yet obſerved. When any one kind of rays has been ſeparated from thoſe of other kinds, it has obſtinately retained it's colours, notwithſtanding all endeavours to bring about a change.

8th, Yet ſeeming tranſmutations of colours may be made, where there is any mixture of divers ſorts of rays; for, in ſuch mixtures, the component colours appear not, but by their mutually alloying each other, conſtitute an intermediate colour.

9th, There are therefore two ſorts of colour, the one original and ſimple, the other compounded of theſe; and all the colours in the univerſe are either the colours of homogenial, ſimple light, or compounded of theſe mixed together in certain proportions. The colours of ſimple light are, as we obſerved before, violet, indigo, blue, green, yellow, orange, and red, together with an indefinite variety of intermediate gradations. The colours of compounded light are differently compounded of theſe ſimple rays, mixed in various proportions: thus a mixture of yellow-making and blue-making rays exhibit a green colour, and a mixture of red and yellow makes an orange; and in any colour the ſame in ſpecie with the primary ones, may be produced by the compoſition of the two colours next adjacent in the ſeries of colours generated by the priſm, whereof the one is next moſt refrangible, and the other next leaſt refrangible. But this is not the caſe with thoſe which are ſituated at too great a diſtance; orange and indigo do not produce the intermediate green, nor ſcarlet and green the intermediate yellow.

10th, The moſt ſurpriſing and wonderful compoſition of light, is that of *whiteneſs*; there is no one ſort of rays which can alone exhibit the colour; it is ever compounded, and to it's compoſition all the aforeſaid primary colours are requiſite.

11th, As *whiteneſs* is produced by a copious reflection of rays of all ſorts of colours, when there is a due proportion in the mixture; ſo on the contrary, *blackneſs* is produced by a ſuffocation and abſorption of the incident light, which being ſtopped and ſuppreſſed in the black body, is not reflected outward, but reflected and refracted within the body till it be ſtifled and loſt.

Having thus endeavoured to give you a general idea of the theory of colours, I ſhall proceed to explain the ſubject more fully, illuſtrating it by the experiments ſo admirably deviſed by Newton. The ſun ſhines favourably for our purpoſe, we will therefore go into the dark room; I have been, you ſee, particularly careful to exclude all light from the room, but what enters through the tube I have fixed in the window-ſhutters. I admit a beam of light through a hole in this tube of about ¼ of an inch diameter, the beam darts through the hole, and forms on the floor an image of the ſun nearly circular. I now place my glaſs priſm ſo as to receive the beam of light, and you obſerve how beautifully that beam is refracted into different coloured rays. The cylindric beam of light paſſes into the priſm, is there dilated, and by refraction thrown into an oblong form, exhibiting on the oppoſite ſide of the room an amazing ſpectrum of colours. The priſm is triangular at each end, about 6 inches long, and is poliſhed on the three ſides. I have placed it parallel to the horizon, with it's axis perpendicular to the beam of light. On turning the priſm ſlowly about it's axis, you ſee that the refracted light on the wall, or the coloured image of the ſun, firſt deſcends, and then aſcends; between the aſcent and deſcent, that is, where the image is ſtationary, the priſm is to be fixed, becauſe in that ſituation the refractions of the light on the two ſides are equal to one another.

Whenever you would have the refractions on both ſides of the priſm to be equal, you muſt note the place on the wall where the image ſtands ſtill, or the mean point between two contrary motions, and there fix the priſm. I ſhall make all the following experiments with the priſm in this ſituation, unleſs ſome other poſition be mentioned.

The refracted light falls perpendicularly upon a ſheet of white paper, placed on the oppoſite wall of the chamber, where an oblong (not an oval) image of the ſolar ſpot is formed; it is terminated by two rectilineal and parallel ſides, and two ſemicircular ends; the ſides are better defined than the ends, which are confuſed and indiſtinct, becauſe the light at the ends decays and vaniſhes by degrees.

The lower extremity is *red*, above this is placed the *orange*, afterwards the *yellow*, then the *green*, the *blue*, the *indigo*, and laſtly the *violet*, which is placed in the upper part of the image. There are, you ſee, innumerable gradations connecting and uniting the primary ones, each colour gradually degenerating as it were into the ſucceeding one. You will not always be able to diſtinguiſh clearly the whole ſeven colours, as it requires a very excellent priſm, and great attention and accuracy in performing the experiment, to prevent ſome of thoſe which moſt nearly reſemble each other, from being confounded together: you will, however, ſcarce ever fail in ſeeing five diſtinctly marked, the lower red gradually declining into a yellow, the yellow ſucceeded by an intenſe green, above this a bright and lovely blue, and then a ſoft but glorious mazarine or violet colour.

The breadth of the ſpectrum anſwers to the breadth of the ſun's circular image. If the priſm had a ſmaller angle, the length of the image would be leſs. If I turn the priſm ſo that the rays emerge more obliquely, the image ſoon becomes an inch or two longer; but if I turn it about the contrary way, ſo as to make the rays fall more obliquely on the ſide neareſt the hole, it ſoon becomes an inch or two ſhorter: therefore in repeating this experiment, you ſhould be careful ſo to place the priſm that the refraction on both ſides may be alike.

This experiment is repreſented *fig.* 9, *pl.* 6. T the tube through which the beam of light enters the room, proceeding in the direction T o I, but is turned out of this direction by a priſm S P D, whoſe axis is perpendicular to the beam; by this the rays of light are refracted ſo as to form a coloured ſpectrum M N upon the ſcreen K L. The moſt refrangible rays being thrown to M furtheſt from I, but the leaſt refrangible being turned leſs out of their courſe, fall upon a part of the ſcreen N, and neareſt I, while thoſe that are refrangible in the intermediate degrees will fall between M and N, forming, inſtead of a circular ſpace, a long ſpectrum bounded by right lined ſides and circular ends, and whoſe length is at right angles to the direction of the axis of the priſm.

The ſize of the hole in the window-ſhutter, the different thickneſs of the priſm through which the rays paſs, the different inclinations of the priſm to the horizon, and the various altitudes of the ſun, make no ſenſible change in the length of the image, nor is it affected by the different matter of which the priſm is formed. With a priſm, whoſe refracting angle is 62 ½ at 18 ½ feet from the priſm, the length of the image is about 9¾ or 10 inches.*

If the rays were equally refrangible, that is, equally inclined to the ſurface of the priſm in the ingreſs and egreſs, their direction would be only changed; the image would be a circle, which will appear ſufficiently clear by your conſidering theſe diagrams. Let A B C, *fig.* 8, *pl.* 6, be a ſection of a triangular priſm at right angles to it's axis. Suppoſe J N to be a ray incident at N, and thence refracted at E on the ſurface C B, where it is again refracted into the ſituation E M. Let *i n* be another ray, parallel to the former, and conſequently incident at *n* with the ſame angle.

Now if the ray *i n* have exactly the ſame capability or diſpoſition to be refracted by the priſm, as the ray J N, the angles of refraction will be alſo equal, and *i n* will, when refracted into the directions n e and m e, ſtill continue parallel to the ray J N, which is refracted into N E and E M.

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* As the light of the ſun is not always to be obtained, I have prepared a ſmall model with coloured ſilk ſtrings, to ſhew the nature and proportion of the coloured rays iſſuing from a priſm.

But if it be more refrangible, it will be refracted into other directions, as n f, and f g, verging more towards the baſe A C; or if it be leſs refrangible, it will be refracted into directions, as n h, and h k, that verge leſs towards the baſe A C.

Whence it appears, that if a collection or pencil of rays fall parallel to each other on one of the ſides of a priſm, and do not proceed parallel to each other on their emergence, it muſt be becauſe ſome of the rays are more refrangible than others.

The preceding experiment therefore with the priſm proves, *that the ſun's light is compoſed of rays whoſe refrangibilities are not all the ſame;* for after emerging from the priſm, inſtead of illuminating a circular ſpace, they are ſpread into a long ſpectrum, bounded by right-lined ſides, and circular ends, and whoſe length is at right angles to the axis of the priſm.

Turn the priſm, which is ſo placed that the axis is perpendicular to the beam of light, that the image may be ſtationary, and there fix it; this being done, look through the priſm at the hole, the length of the image will appear to be many times greater than the breadth; the moſt refracted part being violet, and the leaſt refracted red; the middle parts blue, green, yellow, in order.

Now remove the priſm out of the ſun-beam, and look through it at the hole, and you will have the ſame appearance; if all the rays were equally refracted, the hole would appear round when refracted through the priſm. This therefore, like the preceding experiment, proves that at equal incidences there is a conſiderable inequality of refraction. Beſides the different refrangibility, the foregoing experiments ſhew alſo another remarkable difference between the rays; namely, *that the different refrangibility of the rays is joined with a difference in colour; and all the rays, as they are more or leſs bent by refraction, have a colour peculiar to themſelves.*

To render this ſubject clearer, and to ſhew that theſe appearances are not accidental, but inherent properties of light, Sir I. Newton tried what would be the effect of refracting the rays of light a ſecond time: for this purpoſe he let the light refracted by the firſt priſm fall upon a ſecond priſm, placed at about one foot from the firſt: the firſt priſm was in an horizontal, the ſecond in a vertical ſituation. An image was formed by the ſecond priſm, ſimilar both in the arrangement of colours, and it's dimenſions to that in the firſt experiment, with this only difference, that it was not now in a vertical, but in an inclined poſition. Now if the effects were only cauſed by a modification of light produced by the priſm, the ſecond ought to form in breadth the image that the former made in length, and thus produce a ſquare ſpectrum, which is contrary to the fact. The inclination of the ſpectrum is ſolely occaſioned by the unequal refrangibility; thoſe rays that were moſt bent by the firſt priſm, being alſo by the ſecond; the upper part in both priſms ſuffering a greater refraction, and the lower part a leſs refraction; likewiſe, as before, the upper part appears violet, and the lower part red.

At *fig.* 10, *pl.* 6, is a diagram to illuſtrate this experiment. A B repreſents the ſecond priſm in a vertical direction, that it may again refract the rays which come from the firſt. By the firſt priſm the rays are refracted upwards, by the ſecond ſideways; by the firſt it is refracted to *m n*,

while

while MN is the image formed by the refraction of the two croſs priſms. The breadth of the image is not increaſed; the upper part ſuffers a greater refraction, and the lower a leſs one in both priſms.

If a third, and even a fourth priſm, be placed in the ſame manner after the ſecond, the reſult will be the ſame; and the moſt refrangible rays will ſtill be moſt refracted, and the leaſt the leaſt refracted, whilſt their colours remain unchanged.

Let us now proceed to another experiment. Here, as in the firſt, the light is tranſmitted through a priſm, but the coloured image is received on a ſcreen which I have placed in the middle of the room; there is a hole in the ſcreen, through which the rays of any ſingle colour may be ſuffered to paſs alone, by raiſing or lowering the ſcreen. Thus for inſtance, I place the hole againſt the blue part of the image, ſo that none but the blue rays go through it; theſe are again refracted by a priſm: now you ſee that the blue rays, after having paſſed through the priſm, continue the ſame as before, without any manner of alteration, forming a blue image on the oppoſite ſide of the wall, and the figure of this image is circular. The direction of the beam is altered, but the *rays* are not *dilated or ſeparated into different ſorts*, as the common beam of light was by the firſt priſm. I now move the ſcreen to the *y*ellow rays, and you obſerve that theſe rays falling on the ſecond priſm are refracted to the ſide of the room, and there form only a yellow ſpot, and the ſame with the reſt of the colours; ſo that none of theſe colours are changed by refraction. Further, if you place any ſmall bodies in theſe circular images, they will appear of the ſame colour with the image, red in the red light, green in the green light, &c. ſo that the colours are no ways changed by reflection. Again, if you look at any of theſe ſpots through a priſm, they ſtill preſerve their colour, and are not expanded or dilated in length; ſo that *homogenial* light ſuffers no manner of alteration in any caſe.

In all the trials that have been made, it appears, that thoſe rays which are moſt refracted at firſt, are always moſt refracted; and thoſe that are leaſt at firſt, are always leaſt afterwards. It is therefore plain, *that every ray of light has a peculiar degree of refrangibility, which cannot be changed by any reflections or refractions, but remains conſtantly and invariably the ſame.*

The different refrangibility of the rays of light is a cauſe of confuſion in bodies ſeen through a refracting medium; for this will occaſion the different rays flowing from the ſame point, to be refracted to different points on the retina. Thus, ſmall objects, placed in a ſun-beam, and viewed through a priſm, will be ſeen but confuſedly; but if they are placed in a beam of homogeneous light, ſeparated by a priſm, they will appear as diſtinct through a priſm as when viewed by the naked eye.

As the light reflected from all terreſtrial bodies is the ſolar light, we may fairly conclude from the foregoing experiments, that *the light reflected or emitted from all bodies, conſiſts of rays differently refrangible:* and this may be further proved, for if you look at any object through a priſm, that object will appear tinged with colours. Take a ſmall part of a body, illuminate it ſtrongly, and look at it through a priſm, and you will have an oblong image with all the colours; a ſtar, a lamp, a candle, a burning coal, a red-hot iron, or any burning matter ſeen through a priſm, will preſent you with the ſame appearances.

If you are deſirous of ſeeing a complete ſpecimen of *analytical* reaſoning, you ſhould read SIR

I. NEWTON'S OPTICS, where you will find him purſuing this ſubject in a variety of ways; putting nature to a thouſand proofs, in order to eſtabliſh his deductions on a ſure foundation. It is impoſſible for me to give you even an imperfect idea of this method, in theſe Lectures; it will be ſufficient if you here attain ſo much knowledge as will awaken your attention to a fuller and cloſer inveſtigation of the ſubject. Having ſhewn you by the preceding experiments, that *the light of the ſun conſiſts of rays differently refrangible*, I ſhall now endeavour to prove to you, that *the rays of light, which differ in colour, differ alſo in refrangibility.*

It is not indeed always neceſſary that judgment ſhould be founded on *demonſtration*, in order to obtain your confidence, for demonſtration is rarely to be found. It is expedient, therefore, to ſtudy the art of judging accurately upon *probabilities*, which, where they can be clearly diſcerned, are a ſufficient ground for confidence, until new light break in, or circumſtances change, whereon a new judgment may be formed with ſimilar accuracy. It is the vain expectation of *abſolute certainty* that keeps many continually wavering and irreſolute; for being afraid of truſting to any thing that has not ſuch certainty, and being able to find it no where, they live in a round of doubts, without being able to ſettle on any one point. You may be aſſured that ſome courage, as well as caution, is requiſite, either to ſecure freedom of thought, or open a paſſage to proficiency in any ſcience.

Here is an oblong piece of paper, one half of which is coloured ſtrongly with red, the other with blue; place it upon this piece of black cloth near the window, where it will be ſtrongly illuminated; now look at it through a glaſs priſm, held parallel to it, and to the horizon, with the refracting angle upwards, the paper will appear broken

and

and divided into two parts, the blue half is lifted higher by refraction than the red. If you turn the refracting angle of the priſm downwards, ſo that the paper may be carried lower by refraction, the blue half will be carried lower than the red half. This experiment ſhews clearly, that the light from the blue *is more refracted, and is therefore more refrangible, than the light from the red.*

I ſhall now wrap a thread of black ſilk ſeveral times round a piece of paper, one half of which is coloured like that we uſed in the preceding experiment, and the thread appears as if it were ſo many black lines drawn upon the colours. Darken the room, and ſet the paper up perpendicularly againſt the wall, ſo that one of the colours may ſtand to the right, the other to the left; now illuminate it ſtrongly with a candle, while with a lens of a long focus, I collect the rays, ſo as to form an image of the coloured paper upon the white ſcreen, the ſcreen being at about the ſame diſtance from the lens as the lens is from the coloured paper.

Move the ſcreen backwards and forwards to find where the images of the blue and red parts of the paper are moſt diſtinct; this is eaſily known by the images of the black threads of ſilk, and you will find that where the red half appears diſtinct, the blue half is confuſed; and on the contrary, when the blue half appears diſtinct, the red is ſo confuſed that the black lines are ſcarcely viſible: the ſpace between theſe two ſituations of the paper is about 1 ½ inch, the diſtance of the paper from the lens being about 6 feet. The focal diſtance of the red rays being *longer* than that of the blue, is a proof that the blue rays are more refrangible than the red; and we obtain a new demonſtration of the difference in the refrangibility from the different focal diſtances, at which the rays proceed from different colours; for thoſe whoſe rays are moſt refrangible muſt be collected and united at the ſhorteſt diſtance. Therefore *rays that differ in their colour differ alſo in their degrees of refrangibility.*

The different refrangibility of the rays of light is a great obſtacle to the perfection of teleſcopes and microſcopes. This is a clear inference from our laſt experiment, for no rays iſſuing from a point can be refracted by a lens to a ſingle point.

From what has been ſaid it is alſo plain, that if the ſolar light conſiſted but of one kind of rays, there would be but one colour in the world; or, in other words, all things would be of the ſame colour.

From one experiment to another, Sir I. Newton was led to what he juſtly calls the *experimentum crucis,* which I ſhall relate to you ſo as to enable you to repeat it at your leiſure, as we have already employed as much of our time as can be well ſpared on this ſubject. He took two thin boards, and placed one of them cloſe behind the priſm at the window, in ſuch a manner that the middle of the refracted light might paſs through the hole made in it, and the reſt be intercepted by the board, and be refracted on the other board which he placed at about the diſtance of 12 feet; having made a ſmall hole in the ſecond board alſo, and placed it in ſuch manner that the middle of the refracted light, which came through the hole in the firſt, might paſs through that of the ſecond, the reſt being intercepted by the board might paint upon it the coloured ſpectrum of the ſun.

He then placed another priſm behind the ſecond board, ſo that the light which was tranſmitted through both the boards might paſs through that alſo, and be again refracted before it arrived at the wall.

This being done, he took the firſt priſm in his hand, and turned it about it's axis, ſo as to make the ſeveral parts of the image caſt on the ſecond board ſucceſſively to paſs through the hole therein, and fall upon the priſm behind it, that *he might obſerve to what places on the wall* they would be refracted by the ſecond priſm; and it appeared, that the light which was moſt refracted by the firſt priſm was alſo moſt refracted by the ſecond, and went to the higher part of the wall; and the light which was leaſt refracted by the firſt, was alſo leaſt refracted by the ſecond; and that the moſt refrangible was violet, and the leaſt ſo red. During the experiment the two boards and the ſecond priſm remained unmoved, by which means the incidence thereon was always the ſame; ſo that without any difference in the medium ſome of them ſhall be more refracted than others; and that according to their different degrees of refrangibility they will be tranſmitted through the priſm to different parts of the wall.

Fig. 11, *pl.* 6. V S T is the priſm that firſt receives the ſolar light; this is refracted and falls upon the middle of the board P X Q, the middle part of which falls upon the ſecond board p x q. By turning the priſm V S T ſlowly to and fro about it's axis, the image will be made to move up and down, ſo that all the parts from one end to the other may be made to paſs ſucceſſively through the hole g. a s t another priſm to refract the light paſſing through the hole g on the ſcreen Y Z y. The poſition of the holes remaining conſtantly the ſame, the incidence of the rays on the ſecond priſm was the ſame in all caſes; yet with that common incidence ſome rays are more refracted, and others leſs.

The rays of light that fall on a reflecting ſurface in the ſame angle, if reflected at all, are reflected in the ſame angles; conſequently there will be no ſuch ſeparation in degree of the rays of light by reflection as there is by refraction. This poſition is readily proved. I ſhall place this plane mirror in an horizontal poſition, ſo as to receive this beam from the hole in the window-ſhutter, and it is thereby, you ſee, reflected to the oppoſite wall; the figure of the reflected light is circular like the hole, but there is no ſeparation of the rays as in refraction, nor any colours produced by reflection; the rays, which have the ſame incidence, running parallel to one another after reflection, being reflected at equal angles: though the moſt refrangible will be the ſooneſt reflected, if they move out of a denſe into a rare medium; a circumſtance which does not in the leaſt affect the preſent propoſition.

The rays of the ſun's light, however, which are refrangible, are alſo more reflexible than others. K L I, *fig.* 12, *pl.* 6, repreſents a priſm; the angle K is a right angle; the other angles L, I, are equal to each other; T M a beam of light that paſſes through the ſurface K I, and is incident at N upon L I. It will emerge in the direction M S; but when the angle of incidence at M is ſuch that the ſine of the angle of refraction is equal to the radius, the angle of refraction becoming a right one, the ray cannot emerge, but will be totally reflected.

By turning the priſm ſlowly about it's axis until all the light which went through one of it's angles, and was refracted by it, began to be reflected by it's baſe, Sir I. Newton found, that thoſe rays which had ſuffered the greateſt refraction were ſooner reflected than the reſt; he therefore conceived that thoſe rays of reflected light, which were moſt refrangible, did firſt of all, by a total reflection, become more copious in that light than the reſt; and that afterwards the reſt alſo, by a total reflection, became as copious as theſe. To try this, he made the reflected ray, *fig.* 12, *pl.* 6, paſs through another priſm T V X, ſo placed as to ſeparate it's component colours by refraction; O M, the reflected beam, then the light, which firſt begins to be reflected, conſiſting almoſt entirely of violet light, were by the ſecond priſm ſo refracted as to fall on q, and paint a violet colour. As the firſt priſm continues to be turned on it's axis, the light is more and more copiouſly reflected, and the colours between q and r appear in ſucceſſion till the red appears, when the reflection becoming total, the colours formed by refraction at Q R S diſappear, as thoſe at q s appear.

In the beginning of this Lecture I obſerved to you, that no *one* kind of rays would exhibit whiteneſs; it is the moſt ſurpriſing and wonderful compoſition, an aſſemblage of all the colours of the priſm in union. *Whiteneſs, or the ſolar light, is always compounded; and all the primary colours mixed in due proportion, are requiſite to it's formation.* I ſhall illuſtrate this by one of the moſt celebrated, and moſt ſimple of Sir I. Newton's experiments.

I darken again our room, and, as in the firſt experiment, refract a beam of light by a priſm, and receive it's image on the ſcreen. Let us remove the ſcreen, and hold this lens, ſo that the refracted rays may fall upon it; this you perceive has occaſioned the coloured light, which diverged from the priſm, to unite and meet again at it's focus; and you have, upon a piece of paper held behind the ſolar image intenſely coloured: the rays have no ſooner, you ſee, paſſed through the lens, than they begin to mix and efface each other, and loſe the fine harmonious proportion that was before exhibited in the ſpaces of the coloured image. As you remove the paper from the lens, the colours will approach more and more to each other, and by mixing together will be more and more diluted. You are now at the focus, and, you ſee, they are perfectly mixed together, the colours wholly vaniſh, and are converted into whiteneſs, they forming a ſmall circular image totally white; the red no longer diſplays it's lively flame, the green boaſts no more the livery of the ſpring, nor the blue the lucid robe of heaven, but all blended together exhibit the whiteneſs of the ſun, from whence they proceeded. Remove the paper ſtill further back, ſo as to receive the rays after having croſſed at the focus, and as they diverge you ſee they again renew their ſplendor and colour, but in a contrary order, the red being now above, and the violet below. This reappearance of the colours beyond the place where they were blended, is a further proof of the immutability of the primary colours, as it ſhews that they neither loſe their colour or quality by being blended or interſecting each other, and that the *whiteneſs* which appears is produced only by their *mixture*.

The whiteneſs is made up of all the colours of the image, for if any of the rays be intercepted in their paſſage, the whiteneſs ceaſes, and degenerates into that colour which ariſes from the compoſition of thoſe which were not intercepted, but ſuffered to paſs through the lens; and if the intercepted colour be again let paſs, and fall upon the compound, it will immediately reſtore it's whiteneſs.

That in forming the white the rays do not ſuffer change by acting on each other, is clear; for if you hold the paper beyond the focus of the lens, and ſtop the red colour, the violet ſuffers no change; nor will the red be changed by ſtopping the red, and letting the violet paſs.

When the paper is held at the focus, if you look through a priſm at the white circular image, you will have a coloured ſpectrum; let any ray be intercepted while the image is thus examined, and

then

then let it paſs again, and the colour will appear and diſappear as often as you repeat the experiment, the remaining colours not ſuffering any change; clearly ſhewing, that one colour depends on one kind of rays, and another colour on another kind. So replete and deciſive are the experiments of Sir I. NEWTON, that they not only prove the propoſition they were primarily invented to illuſtrate, but at the ſame time they alſo ſtrengthen the truth of other propoſitions.

Convincing as were theſe experiments, the fertile imagination of NEWTON invented new ones, which, though different from each other, all concurred to prove the ſame thing; they ſeemed to riſe under his hands, as the poets make flowers ſpring under the feet of their beauties.* He cauſed an inſtrument to be made in form of a comb, with teeth 1 ½ inch broad, and at two inches diſtance from each other; by paſſing this comb over the lens placed as in the laſt experiment, part of the colours were intercepted by the teeth, while the reſt proceeded on to the paper placed at the focus of the lens. This image appeared white when the comb was taken away, but when this was interpoſed the whiteneſs was changed into the colour paſſing through the comb. When the motion of the comb is ſlow, the colours red, yellow, green, blue, purple, always ſucceed one another; but when the comb is moved quickly, the colours following one another with extreme rapidity, cannot be diſtinguiſhed, and from the confuſion of the whole there ariſes one uniform colour; the impreſſion of all the colours is at once in the ſame part of the eye, and they jointly excite the ſenſation of whiteneſs.

Here is a top, ſuch as we were uſed to ſpin in our younger days; the ſurface is divided into certain proportions, to accord with the coloured ſpectrum of the priſm: by pulling this ſtring I ſhall make the top revolve rapidly on it's axis; while it is ſo revolving you can diſtinguiſh none of the colours ſingly, but the whole appears white, and this whiteneſs will be greater in proportion as the particular colours are brighter.

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* Algarotti's Philoſophy of Newton explained.

The colours produced by the priſm are not only the moſt beautiful in nature, but each in itſelf continues ſeparate and unalterable. When one of theſe primitive rays has been ſeparated from the reſt, nothing can change it's colour; ſend it through other priſms, refract or reflect it, ſtill it remains unalterable, the red ray preſerves it's crimſon, and the violet it's purple beauty. *Whatever object falls under any of them ſoon gives up it's own colour, though ever ſo vivid, to aſſume the homogenial light of the priſmatic ray.* Take a bit of paper, and place it in the red-making ray, and it will appear red; place it in the other coloured rays, and you will always find it aſſume the radial colour. Take a piece of coloured paper, and put it in the red light, and it will appear red; hold it in the yellow, orange, &c. and it will appear orange, yellow, &c. reſpectively. In ſhort, no art can alter the colour of a ſeparated ray; it gives it's tint to every object, but will aſſume none from any; neither reflection, refraction, nor any other means, can make it forego it's native hue; like gold, it may be tried by every experiment, but will ſtill come forth the ſame.

It will be neceſſary here to explain the method uſed by Sir I. Newton, to define the boundaries of each colour in the priſmatic ſpectrum. You obſerved in the image, that though there was a manifeſt difference of colour not only between the two extremes, but alſo in the intermediate parts, yet the exact place at which any one colour ended and another began was far from being ſufficiently diſtinguiſhable; this indiſtinctneſs was occaſioned by rays of every kind, proceeding from all parts of the ſun's diſk; an entire image of the ſun is projected on the paper, conſiſting of a circle of each particular colour; and as the rays differ in kind by infiniteſimal degrees, from the extreme red to the extreme violet, there muſt, in fact, be thouſands of theſe circles in the oblong image; the centers of which are infinitely near to each other, ſo that the light is intimately mixed, eſpecially in the middle of the image, where it is brighteſt.

He therefore conſidered, that if theſe circles could be made leſs, while their centers kept the ſame diſtances and poſitions, their interference and mixture with each other would be proportionably diminiſhed, and that they would be ſo diminiſhed, if without the room at a great diſtance from the priſm towards the ſun, an opake body was interpoſed, having a round hole in the middle of it, to intercept all the ſun's light, except as much as coming from the middle of it's diſk could paſs through that hole to the priſm; for then the ſeparate circles would no longer anſwer to the whole diſk of the ſun, but only to that part of it which can be ſeen from the priſm through that hole. But to make theſe circles anſwer more diſtinctly to the hole, a lens is to be placed by the priſm, to caſt the image of the hole, that is, of each ſeparate circle diſtinctly on the paper.

At about 10 or 12 feet from the window Sir I. Newton placed a lens, by which the image of the hole might be diſtinctly caſt upon a ſheet of paper at 6, 8, 10, or 12 feet from the lens. Immediately after the lens he placed a priſm, by which the refracted light might be thrown upwards or ſideways; moving the paper that received the image nearer to or further from the priſm, till he found the ſituation, where the ſides of the image were, moſt diſtinct.

Fig. 13, *pl.* 6. F is the hole in the window-ſhutter; M N a lens whereby the image of that hole is caſt diſtinctly on the paper at I; A B C a priſm to refract the rays, emerging from the lens to another paper at p t; the round image at I is thereby turned into an oblong image p t falling on the other paper. This image p t conſiſts of circles placed one after another in rectilinear order, the circles are equal in magnitude to the circle I; conſequently by diminiſhing the hole F, they may be at pleaſure diminiſhed, whilſt their centers remain in their places. By this means the breadth of the image p t may be made forty times, and ſometimes ſixty or ſeventy times leſs than it's length, and thereby the mixture of the rays as much or as little as you pleaſe.

By this means he obtained a diſtinct termination of the images of the hole without any penumbra, and therefore only extending the leaſt degree into each other, and conſequently there was very little mixture of heterogenial rays. By enlarging or diminiſhing the hole in the window-ſhutter, he made the circular images greater or leſs at pleaſure, and thereby the mixture of rays in the oblong image was as much or as little as he choſe; ſometimes making the image 40 times, and ſometimes 60 or 70 times leſs than it's length.

Thus the light was rendered ſufficiently ſimple for trying any of his experiments about homogenial light, the heterogeneous rays being ſo few as hardly to be perceived, excepting in the indigo and violet, which being dark colours eaſily ſuffer an allay, even by the little ſcattering light refracted irregularly by the inequalities of the priſm.

When he had thus got the ſides of the coloured image diſtinctly defined, he delineated the outlines of it on paper, holding the paper ſo that the image might fall on the paper, and coincide with it exactly; while an aſſiſtant marked the confines of each colour, by lines drawn acroſs the image. This was frequently repeated, both on the ſame and different papers; the obſervations were found to agree well enough with each other, and the ſides were divided like a muſical chord, and were in proportion to one another, as the numbers 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{1}{5}$, $\frac{3}{16}$, and $\frac{1}{2}$, and ſo repreſented the chords of the key, and of a tone, a third minor, a fourth, a fifth, a ſixth major, a ſeventh, and an eighth above that key.

The length of the ſpaces, which the 7 primary colours poſſeſs in the ſpectrum, exactly correſponds to thoſe of the chords that ſound the ſeven notes in the diatonic ſcale of muſic.

From this reaſoning, colours and ſounds have been thought to be, in ſome reſpect, ſimilar. There are 7 notes in muſic; there are alſo ſo many primary colours: the diſtance between each note is aſcertained; a ſimilar diſtance is alſo found between each coloured ray. But the diverſities between them are more numerous than the ſimilitudes. The combination of tones increaſes their beauty; but the combination of colours deadens their effect. The ſucceſſion of ſounds have a wonderful influence on the mind; the ſucceſſion of colours has ſcarce any. Notwithſtanding this, Pere Caſtel has written a treatiſe, to prove that as the *ear* finds pleaſure in the ſucceſſion of ſounds; ſo the *eye* may have a ſimilar one from the ſucceſſion of colours. For this purpoſe, he conſtructed an *ocular harpſichord*, which, inſtead of ſounding to the ear, preſented colours to the eye: the priſmatic rays furniſhed the notes, and the ſhades between were ſubſtituted for the ſemitones. Sounds furniſh the ear with all it's pleaſures, but colours furniſh the eye but with half it's pleaſure; therefore, little is to be expected from the muſic of colours. To make ſuch an inſtrument ſatisfy the ſenſe of ſight, the beauty of figure muſt be united to that of colour.

The foregoing principles account for ſeveral phenomena, that were inexplicable before Sir Iſaac Newton had inveſtigated the theory of colours. Among others, why, upon looking at any object through a priſm, the edges only appear tinged with colours, and that in a certain order. Thus, when you look through a priſm, at any object, (if not too ſmall (particularly if it be white), the edges only of the object are coloured; one edge red, orange, and yellow; the other blue, indigo, and violet. Theſe colours are the extremities of ſo many images of the object, as there are rays of light differently refrangible. This will be beſt explained by a diagram. Let A B C D *fig.* 17, *pl.* 6, be a white figure, viewed through a priſm H I K; C E, D E, are rays proceeding from the extremities, which, if the priſm were not interpoſed, would meet at E; but by means of the priſm, are unequally refracted; the red uniting in G, the violet at F; the intermediate one between G and F, into as many points as there are rays differently refrangible. The eye being ſituated ſo as to receive theſe rays, ſees, in this refracted direction, the image a o s p augmented in height, by the quantity b o, which is that of the rays, ſeparated by refraction. The edges of this image are coloured; the lower edge red, from a to e; orange, from c to d; and yellow, between d and e. At the upper edge, blue, from l to m; indigo, from m to n; violet, from n to o. From what we have ſaid, it is eaſy for you to perceive, that theſe colours are the extremities of ſo many images of the object; each colour occupying a ſpace, equal in extent to that of the card A B C D, which receives the light of the ſun, which light is compoſed of all the rays. The red image, therefore, extends from a to b; the orange, from c to i; the yellow, from d to k; the green, from a to l; the blue, from f to m; the indigo, from g to h; the violet, from h to o.

This explains clearly, why the extremities only are coloured, while the middle remains white; the colours anticipate one on the other, ſo that they are all mixed together in the ſpace between h and b; in the ſmall intervals between e and h, and b and l, it is nearly white. It is only from a to e, and from l to o, that the colours are ſufficiently pure and unmixed, to be apparent.

If the object you look at through the priſm is ſmall, and viewed at a diſtance, the whole ſurface is coloured; for when the object is ſmall, each object occupies leſs ſpace; whilſt the quantity that the rays are ſeparated from each other, is the ſame, they are conſequently leſs mixed, and more apparent.

If a black object be ſurrounded with a white one, the colours which are perceived, are to be derived from the light of the illuminated object ſpreading into the regions of the black; and therefore they appear in a contrary order to what they do when a white object is ſurrounded with a black one.

It is the ſame when an object is viewed, the parts of which are leſs luminous than others; for, in the borders of the more and leſs luminous parts, colours ought always to ariſe from the ſame principle, viz. from the exceſs of light of the more luminous object, and to be of the ſame kind as if the darker parts were black, but yet to be more faint and dilute.

What is ſaid of colours made by priſms, may be eaſily applied to the colours made by the glaſſes of teleſcopes and microſcopes, or by the humours of the eye; for if the object-glaſs of a teleſcope be thicker on one ſide than the other, or if one half of the glaſs, or one half of the pupil of the eye, be covered with any opake ſubſtance, the object-glaſs, or that part of it or of the eye which is not covered, may be conſidered as a wedge with crooked ſides: and every other pellucid ſubſtance has the effect of a priſm, in refracting the light that paſſes through it's ſubſtance.

Though the foregoing theory of light and colour was firſt fully and clearly inveſtigated by Sir Iſaac Newton, yet ſome traces thereof are to be found among the ancients.

Plato does not ſeem to have been altogether ignorant of the Newtonian ſyſtem of colours; for he calls them the effect of light tranſmitted from bodies, the particles of which were adapted to the organs of ſight. Now this is preciſely the ſame with what Sir Iſaac teaches, " that the different ſenſations of each particular colour are excited in us by the difference of ſize in thoſe ſmall particles of light which form the ſeveral rays; thoſe ſmall particles of light occaſioning different images of colour, as the vibration is more or leſs lively with which they ſtrike our ſenſes." Plato hath gone further: he has entered into a detail of the compoſition of colours, and inquired into *the viſible effects that muſt ariſe from a mixture of the different rays of which light itſelf is compoſed.* He thought certain rules might be laid down on this ſubject, if, in following and imitating nature, we could arrive at the art of forming a diverſity of colours by the combined intermixture

mixture of others; adding afterwards what may be conſidered as the nobleſt eulogium ever made on Sir *Iſaac Newton*. *Should ever any one*, exclaims this ſublime philoſopher of antiquity, *attempt, by curious reſearch, to account for this admirable mechaniſm, he will, in doing ſo, but manifeſt how entirely ignorant he is of the difference between divine and human power. It is true, God can intermingle thoſe things one with another, and then ſever them at his pleaſure; becauſe he is, at the ſame time, all knowing and all powerful: but there is no man now exiſts, nor ever will, perhaps, who ſhall ever be able to accompliſh things ſo very difficult.* What an eulogium are theſe words, in the mouth of ſuch a philoſopher as *Plato*, and how glorious is *He* who hath ſucceſsfully accompliſhed what appeared impracticable to that prince of philoſophers! And what elevation of genius, what piercing penetration into the moſt intimate ſecrets of nature, diſplays itſelf even in the paſſages recited from Plato, when we conſider that philoſophy was then but in it's infancy.

LECTURE XX.

OF THE RAINBOW.

WHEN we look back upon the knowledge of the ſeveral periods of time with which hiſtory has left us any acquaintance, and compare it with the preſent, reviewing at the ſame time the improvements of the two laſt centuries, and comparing them with the whole ſeries of what preceded, we can ſcarce avoid regarding the later period with a reſpect that approaches to veneration.

It is not to be doubted but that men have at all times the ſame natural abilities. That many of the ſages of antiquity were men of the greateſt ability, and moſt extenſive genius, they have left ſufficient evidence in the records of their works. The glory of the preſent period is, that genius and application have been directed into a proper courſe, that men have ſtudied *things* inſtead of *words*, and have built their ſyſtems upon facts, not like their predeceſſors on theories.

I would not be underſtood as deſirous of taking from the venerable fathers of erudition, all claim to uſeful diſcoveries; for their writings give us teſtimony of inventions which the moſt enterprizing geniuſes of theſe ages have found it impoſſible to equal; but theſe are few. With us knowledge is the offspring of experiment, and we advance nothing as a principle, but what is in a degree demonſtrable, and what can be in ſome way put to the teſt of experience. On this ſtable foundation ſcience has riſen to it's preſent height, a ſituation in which the moſt ſanguine of the writers in the obſcurer ages could never have expected to ſee it; and yet far below that degree of perfection to which I think it poſſible it may arrive, and to which by theſe very means it may be carried. It is not eaſy to ſay what will be the triumphs of modern application joined to modern genius, nor to ſay where it will ſtop, while there is the ſame ardour in the purſuit, the ſame principles to work upon, and an infinite number of facts aſcertained.

The colours of the *rainbow*, which ſtruck antiquity with amazement, no longer now create the philoſopher's ſurpriſe. To Pliny and Plutarch it appeared as an object which we might admire, but could never explain. Kepler ſeems to have been the firſt who ſuppoſed that it might ariſe from the refraction of the ſun's rays upon entering the rain drops. Antonio de Dominis enlarged a theory juſt hinted at by Kepler. Each ſucceeding philoſopher went on in improving a theory, the truth of which ſeemed to carry great probability; but as they were ignorant of the true cauſes of colour, they left the taſk unfiniſhed for NEWTON to complete. You will find that the theory of the rainbow, as explained by him, is full, clear, and will impreſs your mind with perfect conviction.

Of the various meteors the *rainbow* is one of the moſt pleaſing; it's colours not only delight the eye with the mildneſs of their luſtre, but encourage the ſpectator with the proſpect of ſucceeding ſerenity. It is almoſt needleſs to deſcribe this meteor, as there are very few but muſt have ſurveyed it with pleaſure and ſurpriſe. You know that it is only ſeen when the ſpectator turns his back to the ſun, and when it rains on the oppoſite ſide. It's colours, beginning from the under part, are violet, indigo, blue, green, yellow, orange, red, ſo that it contains all the beautiful and ſimple ſhades of the priſm; without the firſt, there is often an external rainbow, whoſe colours are leſs vivid and ranged in an oppoſite order, beginning from the under part, red, orange, yellow, green, blue, indigo, violet. Sometimes we ſee half, ſometimes an whole bow; frequently one, very often two, nay three have been ſeen. Though the rainbow is generally formed by the reflection of the rays of the ſun's light, from the drops of falling rain, it frequently appears among the waves of the ſea, whoſe heads or tops are blown by the wind into ſmall drops; it is alſo ſometimes to be ſeen on the ground, when the ſun ſhines on a very thick dew. Caſcades and fountains, whoſe waters in their fall are divided into drops, will exhibit rainbows to a ſpectator, properly ſituated, during the time of the ſun's ſhining. This appearance is alſo ſeen by moon-light, though ſeldom vivid enough to render the colours diſtinguiſhable; and an artificial rainbow may even be produced by candle-light on the water, which is ejected by a ſmall fountain, or jet d'eau. All theſe are of the ſame nature, and dependent on the ſame cauſes, ſome idea of which may be formed by conſidering theſe diagrams.

Let the circle S t D, *fig.* 12, *pl.* 7, and G d s, *fig.* 13, *pl.* 7, repreſent two drops of water; S s, *fig.* 12, a ray of light falling obliquely on the drop of water at s, inſtead of continuing in it's direction towards F, is refracted to t, whence it will be in part reflected to e, making the angle of incidence equal to the angle of reflection, where, inſtead of going on directly to f, it will be again refracted by paſſing obliquely out of the water into the air.

But as this ray of light conſiſts of a pencil of rays, ſome of which are more refrangible than the others, the violet which is moſt ſo will proceed towards B, and the red, which is the leaſt, towards O. If then the eye of the ſpectator be ſo placed at O, that

the

the ray of light falling upon it from the drop of water has been once reflected and twice refracted, ſo that e o ſhall make with the ſolar ray s S an angle S F O of 42° 2′, he will ſee the red ray in the direction o r; for it has been found by computation, that the greateſt angle, under which the moſt refrangible rays, after one reflection, can come to the eye of a ſpectator, is 40° 17′; and that the greateſt angle under which the leaſt refrangible rays come to the eye is 42° 2′.

If the eye be afterwards raiſed to B, ſo that the ray e b forms with the ſolar ray only an angle of 40° 17′, he will ſee the violet ray in the direction b B, and the intermediate colours at intermediate directions. The ſame thing takes place if the eye of the ſpectator remaining in the ſame ſpace O, the drop of water deſcends from D to E; or if you ſuppoſe this ſpace filled with drops of water, you will then ſee at the ſame time all the priſmatic colours. The rays which have the intermediate degrees of refrangibility will come moſt copiouſly from drops between D and E, and exhibit the intermediate colours in the order which their degree of refrangibility requires.

Now what has been ſaid of one globe or drop of water, is true of millions of drops. Let us now imagine a number of ſuch drops of rain, placed in the circumference of a ſemicircle, in the center of which is the eye of the ſpectator, and we ſhall have a ſemicircular band, adorned with the ſeven primitive colours, and whoſe breadth will be equal to D E, that is, in proportion to the difference between the moſt and leaſt refrangible rays.

To explain the exterior bow, let us ſuppoſe a ray of light S s, *fig.* 13, from the ſun falling obliquely on a drop of water repreſented by the circle G d s; inſtead of continuing in it's original direction to a, it is refracted to d, from whence it will be in part reflected to e; falling again on the concave ſurface, a part will be again reflected towards g, inſtead of g o, where it will paſs into the air again, and be refracted a ſecond time. This ray of light, like the preceding, will be now decompoſed; the red, which is the leaſt refrangible, will proceed to O, and the violet, which is the moſt ſo, to B. Now an eye ſituated at O, ſo as to receive the ray of light, which having been twice refracted and twice reflected by the drops of water, makes with the ſolar ray an angle S h O of 50° 55′, will ſee the red in the direction O r; if the eye is lowered to B, ſo that the angle S h B is 54° 7′, it will perceive the violet ray; and in proceeding from O to B, all the priſmatic colours ſucceſſively.

It has been found, that the ſmalleſt angle under which the leaſt refrangible rays can come to the eye after two reflections is 50° 7′, and that the ſmalleſt angle under which the moſt refrangible can come is 54° 7′. Hence, if the ſun were a point, the diameter of the exterior bow would be 3° 10′, and that of the interior bow 1° 45′, and the diſtance between them 8° 55′; but as his body ſubtends an angle of 32′, 5″, each bow will be increaſed by that quantity, and their reciprocal diſtance diminiſhed.

The ſame effects would take place if the eye of the obſerver was fixed at O, and the drop of water aſcended from G to H; or if you ſuppoſe this ſpace filled up with drops of water, all the priſmatic colours will be ſeen at the ſame time, the drops between G H ſtriking the ſenſe with the intermediate colours, in the order of their refrangibility. If, as in the preceding caſe, you imagine a ſeries of ſuch drops ſituated in the circumference of a ſemicircle, in whoſe center is the eye of the ſpectator, you will have a ſecond ſemicircle, enriched with ſeven primitive colours, but in contrary order to the firſt bow. Thus there will be formed two bows of colours, an interior and ſtronger by one reflection in the drops, and an exterior and fainter by two reflections, the light becoming fainter by every reflection: their colours will be in a contrary order to each other, the red of both bows bordering upon the ſpace which is between the bows.

What has been here only ſuppoſed, really takes place when rain falls; ſo that when the rain and the ſun (with regard to the ſpectator's horizon) are in oppoſite parts of the heaven, there is a ſufficient number of drops in a proper ſituation for the emergent rays to form with the incident rays the angles neceſſary to produce a rainbow. Let E, F, G, H, *fig.* 11, *pl.* 7, repreſent drops of rain, on which the ſolar rays S E, S F, S G, S H, are incident; theſe rays, after having been twice reracted at E and F, and once reflected, fall upon the eye at O. The angle S E O formed by the incident ray S E, and the emergent ray E O being 40° 17′, the violet colour will be perceived at E; the angle S F O, formed in the ſame manner by the incident ray S F, and the emergent ray F O, being 42° 2′, the red is perceived at F; the drops of rain between T and F ſending to the eye the neceſſary emergent ray for producing the intermediate colours.

Thus alſo the rays S G, S H, after two refractions and two reflections, are alſo directed towards the eye placed at O. The angle S G O, formed by the incident ray S G, and the emergent ray G O, being 50° 57′, the red is ſeen at G; the angle S H O, formed by the incident ray S H, and the emergent ray H O being 54° 7′, the violet is ſeen at H; the other drops of rain which are between G and H furniſh the intermediate colours. The ſame may be ſaid of the reſt of the drops conſtituting the two ſemicircular bands A F B E, C H D G.

This may be illuſtrated by experiment, for if the rays of light fall on the ſurface of a glaſs ſphere filled with water, they will be refracted to the other ſide, and there exhibit a coloured ſpot of refracted light; from this part the rays will be reflected to another part of the lower ſurface, and there be refracted a ſecond time into the air, and dilated into all the different coloured rays, ſo that if a perſon's eye was placed under ſuch a globe, he would obſerve all the different colours appear in that globe. For this purpoſe here is a globe filled with water, which I ſhall ſuſpend in a ſun-beam, at ſuch a height that you may eaſily obſerve this phenomenon. You ſee it now receives the light on the upper part, refracts it from the lower into all it's different coloured rays, forming thereby a circle of coloured light on the floor much reſembling the rainbow. Now if you place yourſelf in ſuch manner, reſpecting the globe, that the rays of light of different colours may ſucceſſively fall upon the eye, then you will ſee all thoſe colours in the globe which before formed the variegated arch upon the floor.

This is a caſe exactly ſimilar to the rainbow; for if this globe of water was placed in the heavens, it is evident that the ſun-beams would be refracted through it as they are here.

To illuſtrate the nature of the ſecond bow, we muſt let the ſun-beam fall upon the lower part to the globe; you ſee plainly the coloured ſpot behind to which it is refracted; caſt your eye on the upper part, and you perceive the point to which it is reflected, from whence it is a ſecond time reflected to the fore part of the globe; and from thence you ſee it a ſecond time refracted out of the globe into the air, and the beam thereby diſſipated into all it's different coloured rays; and you ſee by the colours on the floor, that the ſeveral rays in the beam lie in a different order from what they did when refracted from the globe before:

and alſo you will perceive, that the colours of the beam are more dilute and faint than they were in the firſt experiment.

It was by this experiment that Antonio de Dominis undertook to explain the cauſe of the rainbow. Filling a glaſs globe with water, hung at a certain height, oppoſite to the ſun, and ſtanding himſelf with his back to the ſun, and his face to the globe, he found that when this was in ſuch a ſituation that a ray darting from the ſun to the globe made an angle with another ray going from his eye to the globe of 42° 3′, he found the globe appeared red. If the poſition of the globe was altered, ſo as to make the angle between the ſolar and viſual ray leſs, then the other colours of the rainbow aroſe from red down to violet, which appeared at an angle of 4° 17′.

You will now be able to account for all the phenomena of the rainbow; it appears always of the ſame breadth, becauſe the degrees of refrangibility of the red and violet rays which form the extreme rays are always the ſame. The rainbow forms a greater or ſmaller portion of a circle. Our eye is a point of a cone, and the rays that proceed from it at the above-mentioned angles form the ſurface of the cone; the coloured circle is the baſe, part of which is viſible, while the earth cuts off the part which lies above the horizon. The portion in view is of courſe greater or ſmaller, as the line of ſight is more or leſs inclined to the horizon; this obliquity increaſes in proportion to the elevation of the ſun; conſequently the ſize of the bow diminiſhes as the altitude of the ſun increaſes. To make this plainer, ſuppoſe the ſpectator on the top of a very high mountain, and the rain falling at ſome little diſtance from him, inſtead of a ſemicircular rainbow he would then ſee a complete ring of that beautiful meteor; a circle not like our common bow, cut off by the earth, but complete and beautiful; and ſuch is uſually ſeen from the American Andes.

From hence we ſee why there is no rainbow, when the ſun is above a certain altitude; the conical ſurface under which it becomes viſible being below the horizon, when the altitude of the ſun is more than 42 degrees; if the altitude is more than 42, but leſs than 54, the exterior bow may be viſible, though the interior bow is inviſible. Sometimes the rain does not occupy a ſpace extenſive enough to complete the bow, only a portion of an arch will in ſuch caſes be viſible; and the appearance of this portion, and even the bow itſelf, will be various, according to the nature of the ſituation and the ſpace occupied by the rain.

OF THE SEPARATION OF THE ORIGINAL RAYS OF LIGHT, BY REFLECTION OR TRANSMISSION, BUT DEPENDING ON THE THICKNESS OF THE MEDIUM UPON WHICH THEY ARE INCIDENT.

The foundation of a rational theory being laid, it next became natural to inquire by what peculiar mechaniſm in the ſtructure of each particular body, it was fitted to reflect one kind of rays more than another. This Sir I. NEWTON attributes to the denſity of theſe bodies. This ſubject is not ſo clear as the preceding; the preſent theory ſuggeſts many doubts to every inquiſitive mind, and is allowed by all to be attended with difficulties. There are no optical experiments, however, in which Sir I. NEWTON ſeems to have taken more pains, than thoſe relating to the rings of colours which appear in *thin plates*, and which I am going to explain to you; in all his obſervations and inveſtigations concerning them, he diſcovers the greateſt ſagacity, both as a philoſopher and a mathematician.

The bubbles which children blow with a mixture of ſoap and water, were obſerved by Dr. Hooke to exhibit various colours according to their thinneſs, and that when they have a conſiderable degree of thickneſs they appear colourleſs; from this the preſent theory has taken it's riſe. It is thus that things overlooked by the reſt of mankind, are often the moſt fertile in ſuggeſting hints to thoſe who are habituated to reflection.

SIR I. NEWTON blew up a large bubble from a ſtrong mixture of ſoap and water, and ſet himſelf attentively to conſider the different changes of colour it underwent, from it's enlargement to it's diſſolution. He in general perceived that the thinner the plate of water which compoſed the ſides of the bubble, the more it reflected the violet colour ray; and that in proportion as the ſides of the bubble were more thick and denſe, the more they reflected the red: he therefore was induced to believe, that the colours of all bodies proceeded from the thickneſs and denſity of the little tranſparent plates of which they are compoſed. To bring this opinion nearer to certainty, it was neceſſary to meaſure the thickneſs of the plate of water which compoſed the bubble, but this was a matter of great difficulty, as the bubble was of itſelf of too tranſient a nature to undergo the neceſſary experiments.

Sir Iſaac, who was ever fertile in expedients, recollected having obſerved, that as two priſms were compreſſed hard together, in order to make their ſides (which happened to be a little convex) touch one another, they were both as perfectly *tranſparent* in the place of contact as if they had been but one piece of glaſs; but that round the point of contact, where the glaſſes were a little ſeparated from each other, *rings of different colours* appeared.

To obſerve more accurately the order of the colours produced in this manner, he placed a glaſs lens, whoſe convexity was very ſmall, upon a plain glaſs. Now it, is evident, that thoſe would only touch at one particular point; and therefore, at all other places between the adjacent ſurfaces, a thin plate of air was interpoſed, whoſe thickneſs increaſed in a certain ratio, according to the diſtance from the point of contact.

He preſſed theſe glaſſes ſlowly together, by which means the colours very ſoon emerged, and appeared diſtinct to a conſiderable diſtance; next to the pellucid central ſpot made by the contact of the glaſſes, ſucceeded blue, yellow, white, yellow and red. The blue was very little in quantity, nor could he diſcern any violet in it; but the yellow and red were very copious, extending about as far as the white, and four or five times as far as the blue. The next circuit immediately ſurrounding theſe conſiſted of violet, blue, green, yellow, and red; all theſe were very copious except the green, which was very little in quantity, and ſeemed more faint and dilute than the other colours. The third circle of colours was purple, blue, green, yellow, and red; in this the purple was more reddiſh than the violet in the former circuit, and the green was more conſpicuous, being as bright and copious as any of the other colours, except the yellow; the red was alſo ſomewhat faded. The fourth circle conſiſted of green and red; the green was copious and lively, inclining on one ſide to blue, on the other to yellow, but there was neither violet, blue, nor yellow; and the red was very imperfect and dirty. Each outer circuit or ring was more obſcure than thoſe within, like the circular waves upon a diſturbed ſheet of water, till they at laſt ended in perfect whiteneſs.

As the colours were thus found to vary according to the different diſtances of the glaſs plates from each other, Sir Iſaac judged that they proceeded from the different thickneſs of the plate of air, intercepted between the glaſſes; and that this plate was by the mere circumſtance of thinneſs or thickneſs diſpoſed to reflect or tranſmit this or that particular colour; from whence he concluded, as before obſerved, that the colours of all natural bodies depended on their component particles. He alſo conſtructed a table, wherein the thickneſs of a plate, neceſſary to reflect any particular colour, was expreſſed in parts of an inch, divided into 1,000,000 parts.

The appearance of theſe circles, when the glaſſes were moſt compreſſed, ſo as to make the black ſpot appear in the center, is delineated *fig.* 15, *pl.* 7, where a, b, c, d, e; f, g, h, i, k; l, m, n, o, p; q, r; s, t; u, x; y, z, denote the colours reckoned in order from the center, viz. black, blue, green, yellow, red, purple, blue, green, yellow, red; green, red; greeniſh blue, red; greeniſh blue, reddiſh white.

I have already obſerved to you, that the thin plates, made uſe of in the former experiments, reflected ſome kinds of rays in particular parts, and tranſmitted others in the ſame parts. Hence the coloured rings appeared variouſly diſpoſed, according as they were viewed by reflected or tranſmitted light; that is, according as the plates were or were not held up between the eye and the window. That you may underſtand this better, here is a table, on one ſide of which are mentioned the colours appearing on the plates by reflected light, and on the other thoſe which were perceived when the glaſſes were held between the eye and the window. The center, when the glaſſes were in full contact, was perfectly tranſparent; this ſpot therefore, when viewed by reflected light, appeared black, becauſe it tranſmitted all the rays; and for the ſame reaſon it appeared white, when viewed by tranſmitted light.

Colours by reflected light.	*Colours by tranſmitted light*
Black	White
Blue	Yellowiſh Red
White	Black
Yellow	Violet
Red	Blue
Violet	White
Blue	Yellow
Green	Red
Yellow	Violet
Red	Blue
Purple	Green
Blue	Yellow
Green Yellow Red	Red Bluiſh Green
Green	Red
Red	Bluiſh-green
Greeniſh-blue	Red
Red	

In comparing the rings produced by tranſmitted with thoſe produced by reflected light, the white was found oppoſed to the black; the red to the blue, the yellow to the violet, and the green to a colour compoſed of red and violet; in other words, the parts of the glaſs, that when looked at were white, appeared black on looking through the glaſs; and on the contrary, thoſe which appeared black in the firſt inſtance, appeared white in the ſecond; and ſo of the other colours, which you will more readily comprehend by conſidering this figure, where A B, C D, *fig.* 17, *pl:* 7, repreſent the glaſſes which touch at E; the black lines traced between them are the diſtances between the two ſurfaces, at different diſtances from the center, each diſtance anſwering to a coloured ring; the colours written above are thoſe ſeen by reflected light; thoſe underneath, are the colours exhibited by tranſmitted light. Newton has ſhewn, that the rays of any particular colour are diſpoſed to be reflected, when the thickneſſes of the plate of air are as the numbers 1, 3, 5, 7, 9, 11, &c. and that the ſame rays are diſpoſed to be tranſmitted at the intermediate thickneſſes, which are as the numbers 0, 2, 4, 6, 8, 10, &c.

The places of reflection or tranſmiſſion of the ſeveral colours in a ſeries, are ſo near each other, that the colours dilute each other by mixture; whence the number of ſeries, in the open day-light, ſeldom exceeds 7 or 8. But if the ſyſtem be viewed through a priſm, by which means the rings of various colours are ſeparated, according to their refrangibility, they may be ſeen on that ſide towards which the refraction is made, ſo numerous that it is impoſſible to count them. Or, if in a dark chamber the ſun's light be ſeparated into it's original rays, by a priſm, and a ray of one uncompounded colour be received upon the two glaſſes, the number of circles will become very numerous, and both the reflected and tranſmitted light will remain of the ſame colour as the original incident ray. This experiment ſhews, that in any ſeries, the circles formed by the leſs refrangible rays exceed, in magnitude, thoſe which are formed by the more refrangible; and, conſequently, that in any ſeries, the more refrangible rays are reflected at leſs thickneſſes than thoſe which are leſs refrangible.

Water applied to the edges of the glaſs, is attracted between them; and, filling all the intercedent ſpace, becomes a thin plate of the ſame dimenſions as that which before was conſtituted of air: in this caſe, the circular rings grew leſs, and the colours were fainter, but not varied in ſpecies. They were contracted in diameter, nearly in proportion of 7 to 8, and conſequently, the intervals of the glaſſes, at ſimilar circles, as cauſed by theſe two mediums, are as about 3 to 4; that is, as the ſines of refraction out of water into air.

I have already mentioned to you the variety of colours produced by bubbles blown in ſoap-water: but, as theſe colours are commonly too much agitated by the external air to admit of any certain obſervation, it is neceſſary to cover the bubble with a clear glaſs,* in which ſituation you will find the following appearances: the colours emerge from the top of the bubble, and as it grows thinner, by the ſubſidence of the water, they dilate into rings parallel to the horizon, which deſcend ſlowly, and vaniſh ſucceſſively, at the bottom. This emergence continues till the water at the upper part of the bubble becomes too thin to reflect the light, at which time, a circle of an intenſe blackneſs appears at the top, which ſlowly dilates, ſometimes to three quarters of an inch in breadth, before the bubble breaks. Reckoning from the black central ſpot, the reflected colours are the ſame, in ſucceſſion and quality, as thoſe produced by the aforementioned plate of air; and the appearance of the bubble, if viewed by tranſmitted light, is ſimilar to that of the plate of air, in like circumſtances.

Take very thin plates of talc, or Muſcovy glaſs, that exhibit theſe colours; then, by wetting the plates, the colours remain as before, but become more faint and languid, eſpecially when wetted on the under ſide. So that the thickneſs of any plate, requiſite to produce any colour, ſeems to depend only on the denſity of the plate, not on the denſity of the incloſing medium. But the colours are more vivid, as their denſities are different.

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* Nicholſon's Introduction to Philoſophy, vol. i. p. 283.

If two pieces of plate-glaſs, or even common glaſs, be previouſly wiped, and then rubbed together, they will ſoon adhere, with a conſiderable degree of force, and exhibit various ranges of colours, much broader than thoſe obtained by lenſes. One of the moſt remarkable circumſtances attending this method of making the experiment, is the facility with which the colours may be removed, or even made to diſappear, by heats too low to ſeparate the glaſſes. A touch of the finger immediately cauſes the irregular rings of colours to contract towards their center, in the part touched.

From theſe experiments it appears plain, that the colours of bodies depend, in ſome degree, upon the thickneſs and denſity of the particles that compoſe them.

Hence, if the denſity, or ſize of the particles, in the ſurface of a body, be changed, the colour is likewiſe changed.

When the thickneſs of the particles of a body is ſuch, that one ſort of light, or one ſort of colour, is reflected; another light, or other colours, will be tranſmitted; and therefore, the body will appear of the firſt colour.

A certain determinate thickneſs ſeems to be neceſſary in a plate of water; for example, in order to reflect a particular colour, and a different thickneſs, to make it reflect any other colour; and, in general, that a leſs thickneſs is neceſſary, to reflect the moſt refrangible rays, as violet and indigo, than thoſe which are leaſt refrangible, as red and orange.

The particles of bodies reflect rays of one colour, and tranſmit thoſe of another: and this is the ground of all their colours.

OF THE TRANSIENT STATE INTO WHICH A RAY OF LIGHT IS PUT, IN IT'S PASSAGE THROUGH ANY REFRACTING SURFACE, WHICH, IN THE PROGRESS OF THE RAY, RETURNS AT EQUAL INTERVALS; AND DISPOSES THE RAY, AT EVERY RETURN, TO BE TRANSMITTED, AND BETWEEN THE RETURNS, TO BE REFLECTED TO IT.

In order to account for the intervals of the coloured rings in theſe thin plates, and alſo all other caſes of the reflection or tranſmiſſion of light, Sir Iſaac Newton advances an hypotheſis; but, like a wiſe man, and cautious philoſopher, he profeſſes not to lay much ſtreſs upon it, though he ſeems not to entertain any ſuſpicion of it's truth. Indeed, it ſeems to be a kind of fair inference from the preceding experiments.

The hypotheſis is this: that every ray of light is, at it's firſt emiſſion from the luminous body, put into *a tranſient ſtate or conſtitution*, which, in it's progreſs, returns at equal intervals, diſpoſing it, at every return, to be eaſily tranſmitted into any refracting ſurface it may meet with; whereas in the intervals between theſe returns, it is diſpoſed to be eaſily reflected; ſo that, upon the arrival of a number of rays of light at the ſurface of every medium, thoſe of them in which they were diſpoſed to be tranſmitted eaſily, would paſs the interval between the two mediums; and thoſe which were in a contrary ſtate, would be reflected; on which account, ſome light is generally reflected, and ſome tranſmitted, at every different ſurface on which it falls. Thoſe ſtates, into which the rays of light are put, he calls *fits of eaſy reflection and tranſmiſſion.*

This

This hypotheſis, is not without difficulties, and muſt, therefore, be received with caution, as it was propoſed, till it ſhall be either confirmed or confuted by experiment, and a new theory ſubſtituted in it's place.

When arrived, as it were, at the confines of material nature, you muſt expect to meet with ſome confuſion and darkneſs in our explanations. There are barriers to our knowledge, which cannot be paſſed by any force of human faculties. Sir Iſaac Newton, the legiſlator of philoſophers, expreſſed, under the form of conjectures or queſtions, thoſe things which he was unable ſatisfactorily to reſolve; avoiding raſh aſſertions, which are ſo fondly taken up by thoſe who wiſh to ſeduce mankind.

He conjectured, that theſe fits of eaſy reflection and tranſmiſſion may be occaſioned by the vibrations of a *ſubtil fluid*, in which the ray paſſes; any ray being diſpoſed to be tranſmitted when the vibration coincides with it, and to be reflected when it is thereby counteracted.

He alſo thought that theſe vibrations might be excited by the mutual action and re-action of light of bodies, and of this medium, at the inſtant of refraction and reflection.

Sir Iſaac, therefore, ſuppoſed *two* cauſes of this diſpoſition to be reflected or tranſmitted, when rays of light arrive at any new ſurface. One of them is the regular vibration of the etherial medium, affecting them through the whole of their progreſs from the luminous body; and the other the tremulous motion, or irregular vibration of the ſame medium, at the ſurfaces of bodies, occaſioned by the action and re-action between thoſe bodies and light.

Thus, as ſtones, by falling into water, put the water into an undulating motion; and all bodies, by percuſſion, excite vibrations in the air; ſo the rays of light, by impinging on any refracting or reflecting ſurface, excite vibrations in the refracting or reflecting medium, and by exciting theſe, agitate the ſolid parts of the refracting or reflecting body; and that the vibrations thus excited in this ſubtil refracting or reflecting medium are propagated much after the manner that vibrations are propagated in the air, cauſing ſound, and *moving faſter* than the rays, ſo as to overtake them; and that when any ray is in that part of the vibration which conſpires with it's motion, it eaſily breaks through a refracting ſurface; but when it is in the contrary part of the vibration which impedes it's motion, it is eaſily reflected; and, by conſequence, that every ray is ſucceſſively diſpoſed to be eaſily reflected, or eaſily tranſmitted by every vibration by which it is overtaken.

OF THE PERMANENT COLOURS OF NATURAL BODIES, AND OF THE ANALOGY BETWEEN THEM AND THE COLOURS OF THIN TRANSPARENT PLATES.

You have already ſeen, that the colours of natural bodies conſiſt in a diſpoſition to reflect one ſort of rays more copiouſly than another; and that other bodies are of a different colour, becauſe they reflect rays of a different kind. So that if light conſiſted only of one kind of rays, there could be only one colour in the world; nor would it be poſſible, by refractions and reflections, to produce a new one. Thus, in ſome bodies, all the rays are extinguiſhed but the red-making, and when they are reflected to our eyes, they excite in us the idea of red; and thence we ſay, that ſuch a piece of cloth, &c. is red; attributing that only to the cloth or wood, which more particularly ariſes from the light which dreſſes them in their various beauty. Thus the ruby abſorbs the green, the blue, and the violet; but reflects the red-making rays to our eye, with all their priſmatic luſtre. The amethyſt imbibes the ſtronger rays, and gives back the violet with milder brightneſs. The jonquil gives us only yellow, and the hyacinth it's vivid blue. Every coloured object may be thus regarded as a partial divider of the rays, ſeparating one or more colours, and confounding all the reſt.

Thoſe ſurfaces of tranſparent bodies, which have the greateſt refracting power, reflect the greateſt quantity of light. In other words, bodies, by which the light is more refracted, do likewiſe more ſtrongly reflect it. Diamonds, which refract the light very ſtrongly, give it, in proportion, a ſtronger reflection: hence proceed the vivacity of their colours, and their ſparkling luſtre.

The analogy between refraction and reflection will appear, by conſidering that the moſt refractive medium totally reflects the rays of light, at certain degrees of incidence. But the truth of the propoſition further appears, by obſerving the tranſparent bodies, ſuch as air, water, oil, glaſs. Iſland cryſtal, white tranſparent arſenic, and diamond, have a ſtronger or weaker reflection, according to the greater or leſs refractive powers of the mediums that are contiguous to them. Thus at the confine of air and ſal gem, it is ſtronger than at the confine of air and water; and ſtill ſtronger between common air and glaſs; ſtill more ſo between air and a diamond. If any of theſe be immerſed in water, it's reflection becomes weaker than before; and it is weaker ſtill, if it be immerſed in liquors of a greater refractive power. If water be divided into two parts, by any imaginary ſurface, there is no reflection at the confines of thoſe two parts; and for the ſame reaſon, there can be no ſenſible reflection in the confine of two glaſſes of equal denſity. The reaſon, therefore, why all pellucid mediums have no ſenſible reflection but at their external ſurfaces; where they are contiguous to mediums of different denſities, is, that their contiguous parts have preciſely the ſame degree of denſity.

The leaſt parts of all bodies, though ſeemingly void of tranſparency, when viewed in the groſs, will be found, if taken ſeparately, to be, in ſome meaſure, tranſparent: and the opacity ariſes from the multitude of reflections cauſed in their internal parts. This obſervation will be eaſily granted by thoſe who have been converſant with microſcopes; for there they are found to be, for the moſt part, tranſparent. Nothing ſeems more opake, and free from tranſparency, than the cloaths you wear. Yet let us only examine one of the woollen hairs that go into it's compoſition, with a microſcope, and you will find it to be nearly tranſparent. Gold, in the maſs, lets no light paſs through it; but if beaten out extremely thin, we ſhall then ſee that it's parts are tranſparent, like other bodies. If held over a hole, in a darkened window, it will appear of a greeniſh hue. If gold be compoſed of tranſparent parts, we may ſurely conclude the ſame of other bodies: and, indeed, you will find very few which, if reduced to ſufficient thinneſs, and applied to the hole, but what are manifeſtly tranſparent.

Since light finds a free paſſage through the leaſt particles, we are to inquire what renders them opake; and this, by Sir Iſaac Newton, is attributed to the multitude of reflections and refractions which take place in it's interior parts; there being, between the parts of opake or coloured bodies, a number of ſpaces, filled with mediums of a different denſity from that of the body, as water between the tinging corpuſcles with which any liquor is impregnated; air between the aqueous globules that conſtitute clouds and miſts, &c. Theſe ſpaces cannot be traverſed by light, without refracting or reflecting it in various ways, by which it is prevented from paſſing on in a ſtrait line, which it would do if the parts were continuous, without any ſuch interſtices between them; for you have already learned, that reflections are only made at the ſuperficies of mediums of different denſities. The opacity of bodies ariſes, therefore, from the diſcontinuity of it's particles, and the different denſity of the intervening mediums, and their particles.

This notion of opacity is greatly confirmed by conſidering, that opake bodies become tranſparent by filling up the pores with any ſubſtance of nearly the ſame denſity with their parts. Thus when paper is wet with oil or water, or when linen cloth is dipped in water, oiled, or varniſhed, or the oculus mundi ſteeped in water, &c. they become more tranſparent than they were before; as filling the pores of an opake body makes it tranſparent, ſo, on the other hand, evacuating the pores of a tranſparent body, or ſeparating it's parts, renders it opake; as ſalts, or wet paper, by being dried; horn, by being ſcraped; glaſs, by being reduced to powder, or otherwiſe flawed; turpentine, by being ſtirred about with water, till they mix imperfectly; and water, by being formed into many ſmall bubbles, either in the form of froth, or, by ſhaking it together with oil of turpentine, or ſome other convenient liquor, with which it will not incorporate.

Hence, then, it is in homogeneity you are to ſeek for the cauſe of tranſparency. If there be many pores in a body, and theſe be filled with a matter differing much in denſity from the body itſelf, the light will meet with a thouſand refractions and reflections in the internal parts, and will thus be utterly extinguiſhed.

The parts of bodies, and their interſtices, muſt not be leſs than ſome definite ſize, to become opake and coloured.

For the moſt opake bodies, if their parts be ſufficiently divided, as metals, by being diſſolved in acid menſtrua, &c. become perfectly tranſparent. And you may remember, that the black ſpot, near the point of contact of the two plates of glaſs, tranſmitted the whole light where the glaſſes did not abſolutely touch; and the reflection at the thinneſt part of the ſoap was ſo inſenſible as to make that part appear intenſely black, by the want of reflected light.

On theſe grounds it is, that water, ſalt, glaſs, ſtones, &c. are tranſparent, for, from many conſiderations, they ſeem to be as full of pores as other bodies are, yet their particles and pores are too ſmall to cauſe reflection in their common ſurfaces.

The tranſparent parts of bodies, according to their ſeveral ſizes, muſt reflect rays of one colour, and tranſmit thoſe of others, on the ſame principles that thin plates or bubbles do reflect or tranſmit theſe rays; and this ſeems to be the ground of all their colours.

That they do ſo, is plain from various obſervations; and it is on theſe principles you may explain the variety of colours ſeen in ſome ſilks, on pigeons' necks, peacocks' tails, and the feathers of other finely coloured birds. If you fix your eye upon a pigeon's neck, and both be kept at reſt, only one colour is obſervable: but if either moves, eſpecially the latter, a different colour may be ſeen. Shady ſilks are woven, with threads of different colours; one arranged longitudinally, the other tranſverſely; and as the greater or leſs proportion of either of theſe appears, ſo one or the other of the colours will prevail. Wet theſe double coloured objects, dip the variegated feather in water, or the changeable ſilk in oil, their reflections will be leſs vivid, and they will return but one uniform ſhade of colouring. The ſkin of the camelion is tranſparent, it's ground being between a pale red and yellow, coloured with a number of ſmall, ſmooth protuberances of cold, bluiſh colour. It is endowed with a faculty of blowing up or contracting it's ſkin at will. This cauſes the different colours, in appearance, to vary: it, therefore, ſometimes appears reddiſh, at others, blue: the yellow rays of the ground, occaſionally mixing with the blue of the protuberances, produces the idea of green; and when placed on a red or yellow ſubſtance, it's natural colours are unavoidably heightened.

It is evident, from various phenomena, that a great proportion of the fainter coloured rays are ſtopped in their paſſage through the atmoſphere, and are thence reflected upon other bodies; while the red and orange rays are tranſmitted to greater diſtances, This circumſtance explains the blue ſhadows of bodies, the blue colour of the ſky, and the red colour of the clouds, when the ſun is near the horizon.

At certain times, when the ſky is clear and ſerene, in the morning and the evening, the ſhadows caſt from opake bodies have been obſerved to be tinged with blue and green, This circumſtance naturally reſults from the minute particles of the atmoſphere reflecting the delicate and moſt refrangible rays, the blue and violet, for inſtance; which occaſions a predominance of theſe colours.

The blue colour of the ſky is accounted for on the ſame principles; namely, the copious reflection of the blue rays, by the atmoſphere, which produces the effect of an arch of that colour, all around us. This is occaſionally diverſified by the vapours' greater denſity, which reflect the ſtronger rays.

The coloured clouds, in particular, which appear towards the morning and evening, when the ſun is in or near the horizon, are to be attributed to the ſame cauſe. The rays of light traverſing a vaſt extent of atmoſphere; the fainter and more delicate rays, as the blue and violet, are detached by repeated reflections of the atmoſpheric particles; and the ſtronger rays, as the red, the orange, &c. are permitted to proceed, and reach the clouds, from whence they are reflected. Agreeable to this theory, you may obſerve, that the ſun's horizontal light is ſometimes ſo deeply tinctured with the red, that objects illuminated by it frequently appear of a bright orange, and even red. It is obſervable, that the clouds do not, in common, aſſume their brighter dyes till the ſun is ſome minutes ſet, and that they paſs from yellow to a flaming gold colour; and thence, by degrees, to red, which becomes deeper and deeper, till the ſun leaves them altogether, till at length the diſappearance of the ſun leaves them of a leaden hue, by the reflection of the blue light from the air. A ſimilar change of colour is obſerved on the ſnowy tops of the Alps; and the ſame may be ſeen, though leſs ſtrongly, on the eaſtern and weſtern fronts of white buildings: St. Paul's church, London, is a good object of this kind, and is often, at ſun-ſet, tinged with a conſiderable degree of redneſs. What makes the ſame colours more rich and copious in the clouds, is their ſemi-tranſparency, joined with the obliquity of their ſituation.

It is probably the ſame coloured light, which being thrown, by the refraction of the atmoſphere, into the ſhadow of the earth, ſometimes gives the moon, in a total eclipſe, the obſcure, reddiſh colour of brick. For the ſame reaſon, the colour of the moon will vary in eclipſes, according to the extent of the atmoſphere the rays have to traverſe.

MR. DELAVAL'S ACCOUNT OF THE PERMANENT COLOURS OF OPAKE BODIES.

I ſhould leave this ſubject very incomplete, if I did not give you ſome account of the ingenious obſervations of Mr. DELAVAL, extracted from a paper communicated by him to the Literary and Philoſophical Society of Mancheſter, and publiſhed in the ſecond volume of their memoirs.*

Mr. Delaval was led to this ſubject, from a perſuaſion of it's *utility* to thoſe intereſting and elegant arts, whoſe object is the preparation and uſe of colouring ſubſtances: juſtly obſerving, that our views of experimental philoſophy ſhould not be confined to theory alone, but directed alſo to it's practical application.

For, in proportion as the principles of any ſcience are unknown or miſconceived, the advancement of the arts, and manufactures which depend on them, muſt, of courſe, be impeded; for, without thoſe guides, neither much addition, nor any improvement, is to be expected. But when ſcientific principles are diſcloſed to the artiſt, he is enabled to draw, from thoſe original ſources, an ample ſtore of uſeful inventions, by which this art is enriched; and thus, the ſpeculative ſciences, by their extenſion to practical purpoſes, become objects of great public utility.

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* There is another work of Mr. Delaval, written previous to this paper, which is well worth the reader's attention: it is entitled, "An Experimental Inquiry into the Cauſes and Changes of Colours, in Opake and Coloured Bodies."

The arts of colour-making and dyeing were, in very remote ages, carried to the height of perfection, in the countries of Phœnicia, Egypt, Paleſtine, India, &c. The inhabitants of thoſe countries excelled, alſo, in the art of imitating gems, and tinging glaſs and enamel of various colours. The colours uſed in very ancient paintings, were as various as thoſe now in uſe, and greatly ſuperior both in beauty and durability. The paints uſed by Apelles were ſo bright, that he was obliged to glaze his pictures with a dark coloured varniſh, leſt the eye ſhould be offended by their brightneſs: and even theſe were inferior to what had been uſed among the ancient Egyptians. Notwithſtanding this perfection in dyeing and colours, we find the Grecians and Romans continually degrading the uſeful arts. You may conſider this as one of the moſt ſtriking characters that diſtinguiſh the philoſophy of the ancients from that of the moderns. The *ancients* being chiefly engaged in ſpeculations, that might procure them reſpect, and attract applauſe, thought the *uſeful* arts unworthy their attention: whereas the *moderns* have cultivated and promoted the uſeful arts; and we find, the Academy of Sciences of Paris, attempting to ſhed the light of ſcience upon the arts, by publiſhing a deſcription of them, grounded on the elevated idea, that the induſtry of a nation cannot fail to be enlightened and increaſed by a free communication of all the proceſſes it uſes; and that the ſacrifices it makes, by this publicity, will ever be amply compenſated by the advantages it procures.*

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* Berthollet's Elements of Dyeing.

But why need we go to academies, when we have a fairer and better example in our LORD and SAVIOUR? an example which ſhould teach you to avoid the philoſophical *pride* of the gentile, and the phariſaical *ſelf-ſufficiency* of the modern infidel. Of our SAVIOUR we read, that having increaſed in wiſdom, he went about doing good. His learning produced not a moroſe ſelf-complacency, but a lovely affability, and a deſire to teach others the glad tidings of joy. The treaſures of wiſdom were not ſuffered to ruſt and canker, locked up from the public by a ſupercilious reſervedneſs; but out of them he continually diſperſed abroad, and gave to the poor in ſpirit. The ſun, at it's riſing, found him engaged in this great work; and after it was ſet, his time was engaged in praying for thoſe whom his days were employed in teaching.

The changes of colour, in permanently coloured bodies, are produced by the ſame laws which take place in tranſparent colourleſs ſubſtances; and the experiments, by which they can be inveſtigated, conſiſt of various methods of uniting the colouring particles into larger, or dividing them into ſmaller maſſes.

Sir I. Newton made his experiments chiefly on tranſparent ſubſtances; and in the few places where he treats of others, acknowledges his deficiency of experiments. He makes the following remark on thoſe bodies which reflect one kind of light, and tranſmit another; viz. "that if theſe glaſſes or liquors were ſo thick and maſſy, that no light could get through them, he queſtions whether they would not, like other opake bodies, appear of one and the ſame colour, in all poſitions of the eye, though he could not yet affirm it from experience." It was an opinion of this great philoſopher, that all coloured matter reflects the rays of light; ſome reflecting copiouſly the more, others the leſs refrangible rays. He was, likewiſe, of opinion, that opake bodies reflect the light from their anterior ſurface, by ſome power of the body, evenly diffuſed over, and external to it. With reſpect to tranſparent coloured liquors, he ſays, that a tranſparent body, which looks of any colour by tranſmitted light, may alſo look of the ſame colour by reflected light; the light of that colour being reflected by the farther ſurface of that body, or by the air beyond it; and then the reflected colour will be diminiſhed, and perhaps ceaſe, by making the body very thick, and pitching it on the back ſide, to diminiſh the reflections of it's farther ſurface, ſo that the light reflected from the tinging particles may predominate. In ſuch caſe, the reflected light will be apt to vary from that which was tranſmitted.

To inveſtigate the truth of theſe opinions, Mr. Delaval entered upon a courſe of experiments, with tranſparent coloured liquors and glaſſes, as well as with opake and ſemi-tranſparent ſubſtances. From theſe he found, that in tranſparent coloured ſubſtances, the colouring matter *does not reflect any light*; and when, by intercepting the light which was tranſmitted, it is hindered from paſſing through ſuch ſubſtances, they do not vary from their former colour to any other, *but become entirely black.*

As this incapacity of the colouring particles of tranſparent bodies to reflect light, was deduced from very numerous experiments, it may be conſidered as a general law. It will appear the more extenſive, if you conſider that, for the moſt part, the tinging particles of tranſparent ſubſtances are extracted from opake bodies; that the opake bodies owe their colour to theſe particles, as well as the tranſparent; and that by the loſs of them they are deprived of their colours.

For making his experiments, Mr. Delaval uſed ſmall vials of flint-glaſs, ſimilar to that in my hand; the form is that of a parallelopiped, the height excluſive of the neck is about 2 inches, the baſe about an inch ſquare, the neck 2 inches long. The bottom and three ſides of each of theſe vials was covered with a black varniſh; the cylindrical neck, and the anterior ſide, except at the edges, being left uncovered. He was careful to avoid any crevices in the varniſh, that no light might be admitted, except through the neck or anterior ſide of the vials.

The vials ſhould be perfectly clean, and thoſe liquors that depoſit a ſediment ſhould not be put into the vials, but at the time when the experiments are to be made. The uncovered ſide of the vials ſhould not be placed oppoſite to the window where the light is admitted, becauſe in that ſituation the light would be reflected from the fartheſt ſide of the vial; ſmooth black ſubſtances, reflecting light powerfully, are beſt ſituated, when the uncovered ſide forms a right angle with the window.

Taking all theſe precautions, he viewed a great number of ſolutions both of coloured metallic ſalt, and of the tinging matter of vegetables, obſerving that the colour by reflection was black, *whatever it might be* when viewed by tranſmitted light. If theſe colours were, however, ſpread thin upon a white ground, they appear of the ſame colour as when viewed by tranſmitted light; but on a black ground they afford no colour, unleſs the black body be poliſhed, in which caſe the reflection of light through it produces the ſame effect as tranſmiſſion.

The experiments made with coloured glaſſes, were in many reſpects analagous to thoſe with tranſparent coloured liquors. For theſe he made ſeveral parcels of colourleſs glaſs, compoſed of borax and white ſand. The glaſs was reduced to powder, and afterwards ground together with the ingredients, by which the colour was to be imparted; a method he found preferable to the uſual mode of tinging glaſſes, as they became little inferior in luſtre to real gems.

The reſult of all his experiments was, that when matter is of ſuch thinneſs, and the tinge ſo dilute, that light can be tranſmitted through it, the glaſſes then appear vividly coloured; but when they are in large maſſes, and the tinging matter is more denſely diffuſed through them, they appear black, for theſe as well as the tranſparent liquors ſhew their colour only by tranſmiſſion.

Having in this manner formed pieces of ſuch glaſs, two inches thick, he incloſed them in black cloth on all ſides, except their anterior and farther ſurfaces. In this ſituation each of them ſhewed a vivid colour when light was tranſmitted through them, but when the poſterior ſurface was likewiſe covered with the cloth to prevent the tranſmiſſion, no other colour but black was exhibited.

From theſe phenomena he drew the following inferences:

1. *That the colouring particles do not reflect any light.*

2. *That a medium, ſuch as is deſcribed by Sir I. Newton, is diffuſed over both the anterior and poſterior ſurfaces of the plates, whereby objects are equally and regularly reflected as by a mirror.*

Our author next conſiders the colouring particles themſelves, pure and unmixed with other media. To procure maſſes made up of ſuch particles, ſeveral tranſparent coloured liquors were reduced to a ſolid conſiſtence by evaporation; by employing a gentle heat the colouring matter will not be injured, and may have it's particles again ſeparated by water or other fluids, and tinging them as before. In this ſtate alſo the colouring particles reflect no light, and therefore appear uniformly black, whatever be the ſubſtance from which they may have been extracted.

He endeavours to prove by experiments on the colouring particles of opake bodies, that theſe colours are produced on the above-mentioned principles; that they ſeem black when very denſe, but ſhew their proper tinge when ſpread thin upon a white ground.

The green of graſs, and leaves of plants being obtained by digeſting them in rectified ſpirits of wine, and placed in one of the above-mentioned vials, the part in the neck tranſmitted the vivid green, but that contiguous to the uncovered ſide of the vial was black.

After the colour had been totally extracted, the leaves remained apparently unaltered as to figure or texture, but were entirely white, or of a white tinged with brown; red, blue, and purple flowers were alſo digeſted with ſpirits of wine, all of which yielded their colouring matter to the ſpirit, and became white when deprived of it. From moſt of theſe flowers the ſpirit, however, either acquired no tinge at all, or only a very faint one; but when acidulated it became red, and by the addition of an alkali became blue, purple, or green, according to the quantity of the alkali and the nature of the infuſion. In theſe ſtates all of them, when viewed by tranſmitted light, or poured upon a white paper, ſhewed their colours, but univerſally appeared black by reflection. Other experiments were tried with other flowers, but the final reſult was the ſame, *no colour by reflection.*

White paper, linen, &c. may be tinged of any of theſe colours, by dipping them in the infuſions; and the conſideration of the manner in which the colours are imparted to linen, affords much inſight into the manner in which natural colours are produced. It has been already obſerved, that when the colouring matter of plants is extracted from them, the ſolid fibrous parts, thus diveſted of their covering, diſplay their natural *whiteneſs*. White linen, paper, &c. are formed of ſuch fibrous vegetable matter, which is bleached by diſſolving and detaching the heterogeneous colouring particles: when theſe therefore are dyed or painted with vegetable colours, it is evident that they do not differ in their manner of acting on the rays of light from natural vegetable bodies; both yield their colours by tranſmitting through the tranſparent coloured matter the light which is reflected from the white ground.

This *white matter* ever exiſts without any conſiderable mixture in plants while they are in a ſtate of vegetation, as cotton, white flowers, the pith, wood, ſeeds, roots, and other parts of ſeveral kinds of vegetables. When decayed leaves of trees have been long expoſed to the atmoſphere, their coloured juices are ſometimes ſo perfectly extracted that their fibres appear white.

Mr. Delaval has rendered aſhes *intenſely white*, by carefully calcining them, and afterwards grinding with a ſmall proportion of nitre, and expoſing them to ſuch a degree of heat as would cauſe the nitre to deflagrate with the remaining quantity of phlogiſton. Laſtly, the aſhes were digeſted with the marine acid, in order to diſſolve the ferruginous matter diffuſed through them, and repeatedly waſhing the remainder in water.

Hence it would appear, that the earth which forms the ſubſtance of plants is white, and ſeparable from that ſubſtance which gives to each it's peculiar colour; that whenever it is pure and unmixed, or diffuſed through colourleſs media, it ſhews it's native whiteneſs, and is the only vegetable matter endowed with a native whiteneſs. This white matter may be diſcovered by other means beſides burning; thus roſes may be whitened by expoſing them to burning ſulphur, and the colour may be again reſtored by the addition of an acid either mineral or vegetable.

Thus it appears that the colouring matter of the flowers is not diſcharged or removed, but only diſſolved by the phlogiſton, and thereby divided into particles too minute to exhibit any colour. In this ſtate, together with the vegetable juice in which they are diffuſed, they form a colourleſs tranſparent covering, through which the white matter of the flowers is ſeen untinged. The colouring matter of plants conſiſts, according to Mr. Delaval, principally of inflammable matter, and their ſolubility in and union with phlogiſton.

Colour is deſtroyed by the rays of the ſun. Thus dyed ſilk and other ſubſtances of that kind, when expoſed to the ſun's light, are deprived of their colour in every part on which the rays are allowed to act; whilſt thoſe preſerve their colours which are defended from the light. The colours, thus *impaired*, may be reſtored, if acids are employed while the injury is recent.

In a word, all Mr. Delaval's experiments ſhew, that the colouring matter of plants does not exhibit any colour by reflection, but by tranſmiſſion only; that their ſolid earthy ſubſtance is a white matter, and that it is this part that has the property of reflection; that the colours of vegetables are produced by the light reflected from this white, and tranſmitted from thence through the coloured coat or covering which is formed on it's ſurface by the colouring particles; that whenever the colouring matter is either diſcharged or divided by ſolution into particles too minute to exhibit any colour, the ſolid earthy ſubſtance is expoſed to view, and diſplays that whiteneſs which is it's diſtinguiſhing characteriſtic.

Mr. Delaval having ſettled this point, next proceeded to examine the coloured parts of animal ſubſtances, and found them exactly ſimilar with regard to the manner in which the colour was produced, to the vegetable ſubſtances already treated of. The tinctures and infuſions of cochineal and kermes yield their colours when light is tranſmitted through them, but ſhew none by reflection: on diluting freſh ox-gall with water, and examining it in the above-mentioned phials, the part of it viewed by tranſmitted light was yellow; but the anterior ſurface in the lower part of the phial was black, and reflected no colour. Fleſh derives it's colour entirely from the blood, and when deprived of it the fibres and veſſels are perfectly white; as are likewiſe the membranes, ſinews, and bones, when freed from their aqueous and volatile parts. The florid red colour of the fleſh ariſes from the light which is reflected from the white fibrous ſubſtance, and tranſmitted back through the red tranſparent covering, formed by the blood on every part.

In like manner the red colour of the ſhells of lobſters after boiling, is no more than a mere ſuperficial covering, ſpread over the white calcareous earth of which the ſhells are compoſed, and may be removed from the ſurface by ſcraping or filing. Before the application of heat this ſuperficial covering is much denſer, inſomuch that in ſome parts of the ſhell it appears quite black, being too thick to admit the paſſage of the light to the ſhell and back again; but where this tranſparent blue colour of the unboiled lobſter is thinner, it conſtantly appears like a blue film. In like manner the colours of the eggs of certain birds are entirely ſuperficial, and may be ſcraped off, leaving the white calcareous earth expoſed to view.

The caſe is the ſame with feathers, which owe their colours entirely to a very thin layer of ſome tranſparent matter upon a white ground; this was aſcertained by ſcraping off the ſuperficial colours from certain feathers, which were ſtrong enough to bear the operation, and which ſeparated the coloured layers from the white ground on which they have been naturally ſpread. The lateral fibres cannot have their colours ſeparated in this manner; but their texture, when viewed by a microſcope, ſeems to indicate that their colours are produced on them by no other means than thoſe already related. In a word, he found that in all the animal ſubjects he examined, the colours were produced by the tranſmiſſion of light from a white ground through a tranſparent coloured medium.

The coloured ſubſtances of the mineral kingdom are very numerous, and belong principally to two claſſes, earths and metals; the former, when pure, are all white, and their colour ariſes from phlogiſtic or metallic mixtures. Calcareous earths, when indurated, conſtitute marble, and may be tinged with various colours by means of metallic ſolutions, all which are ſimilar in their nature to the dyes put upon ſilk, cotton, or linen, and invariably proceed from the ſame cauſe, the tranſmiſſion of light through a very thin and tranſparent medium. Flints are formed from ſiliceous earths, and owe their colour to the ſtate of fire within them; when ſufficiently heated, they are rendered white by the loſs of the inflammable matter which produced their colour; when impregnated with metals, they form agates, cornelians, jaſper, and coloured cryſtals. The coloured gems alſo receive their different hues from metals, and may be imitated by glaſſes tinged with ſuch inflammable or metallic matter as entered into the original ſubſtances, all exhibiting their various tints in the ſame manner, by the tranſmiſſion of light from a reflected white ground.

Even the colours of metals, according to Mr. D. are produced in the ſame manner. Gold exhibits a white light tinged with yellow; this is grounded on an experiment of Sir I. Newton, who ſays, that gold in a white light appears of the ſame colour as in the day-light, but that on intercepting a due quantity of yellow-making rays, it will appear white like ſilver, which ſhews that it's yellowneſs ariſes from an exceſs of the intercepted rays, tinging that whiteneſs with their colour when they are let paſs.

A ſolution of ſilver is pellucid and colourleſs; a ſolution of gold tranſmits yellow, but reflects no colour. This metal, when united to glaſs, yields no colour by reflection, but only by tranſmiſſion. All theſe circumſtances ſeem to indicate, that the yellow colour of gold ariſes from a yellow tranſparent matter, which is a conſtituent part of that metal, and that is equally mixed with the white particles of the gold, and tranſmits the light reflected by them; in like manner as when ſilver is gilt, or foils are made by covering white metals with tranſparent colours. But theſe factitious coverings are only ſuperficial, whereas the yellow matter of gold is diffuſed throughout the whole ſubſtance of the metal, and appears to envelope and cover each of the white particles; the yellow matter bears to the white about the ſame proportion that the yellow-making rays, which were intercepted, bear to all the other rays compriſed in the white light of the ſun.

Sir Iſaac Newton has ſhewn, that when the ſpaces or interſtices of bodies are repleniſhed with media of different denſities, the bodies are opake; that thoſe ſuperficies of tranſparent bodies reflect the greateſt quantity of light, which intercede media, that differ moſt in their refractive denſities; and that the reflection of thin tranſparent ſubſtances are conſiderably ſtronger than thoſe made by the ſame ſubſtances of a greater thickneſs. Hence the minute portion of air, or of the rarer medium, which occupies the pores or interſtices of denſe bodies, is a minute white ſubſtance. This is manifeſt in the whiteneſs of froth, and of all pellucid colourleſs ſubſtances, ſuch as glaſs, cryſtal, or ſalts reduced to powder, or otherwiſe flawed; for in all theſe inſtances a white light is reflected from the air or rarer medium, which intercede the particles of the denſer ſubſtance, whoſe interſtices they occupy.

Hence alſo we ſee why white opake ſubſtances are rendered pellucid by being reduced to uniform maſſes, whoſe component parts are every where nearly of the ſame denſity; for as all pellucid ſubſtances are rendered opake and white by the admixture of pellucid colourleſs media, of conſiderably different denſities, they are again deprived of their opacity, by extracting theſe media, which keep their particles at a diſtance from each other: thus froth or ſnow, when reſolved into water, loſe their whiteneſs, and aſſume their former pellucid appearance. In like manner the opake white earths are by proper fluxes reduced to pellucid colourleſs glaſs; becauſe all reflections are made at the ſurfaces of bodies differing in denſity from the ambient medium, and in the confines of equally denſe media there is no reflection.

As the calces of metal are capable of reflecting their colours by the intervention of air, ſo, when mixed with oil in making paints, they always aſſume a darker colour, becauſe the exceſs of the denſity of oil over air forms a ſenſible difference, when comparatively conſidered with reſpect to the ſpecific gravity of the rarer metals. From this cauſe perceptibly leſs light is reflected from the moleculæ of oil than from thoſe of air, and conſequently the maſs appears darker. The caſe is however different with ſuch paints as are formed of the denſer metals, as vermillion, minium, &c. for though oil differs very conſiderably from air in it's ſpecific denſity, yet it alſo differs very much in this reſpect from the denſer metallic powders; and the moleculæ of oil, which divide their particles, act upon the light ſo ſtrongly, that the reflection of light occaſioned by them cannot be diſtinguiſhed from thoſe which are cauſed by rarer media. Hence, when we mix vermillion or minium with oil, the colour is not ſenſibly altered.

All the earths, which in their natural ſtate are of a pure white, conſtitute tranſparent colourleſs media when vitrified with proper fluxes, or when diſſolved in colourleſs menſtrua; and the ſaline maſſes, obtainable from their ſolutions, are tranſparent and colourleſs, while they retain the water which is neceſſary to their cryſtallization, and are not flawed or reduced to powder: but after their pores and interſtices are opened in ſuch a manner as to admit the air, they become white and opake by the admittance of that rare medium. The earthy particles, which form the ſolid parts of bodies, generally exceed each other in denſity; conſequently theſe particles, when contiguous to the rare media already mentioned, muſt reflect the rays of light with a force proportionate to their denſity. The reflective power of bodies does not depend merely upon their exceſs of denſity, but upon their difference of denſity with reſpect to the ſurrounding media. Tranſparent colourleſs particles, whoſe denſity is greatly inferior to that of the media they come between, alſo powerfully reflect all ſorts of rays, and thereby become white; of this kind are the air, or other rare fluids, which occupy the interſtices of liquors, and in general of all denſer media, where ſuch rare particles are admitted.

Hence we may conclude, that white opake bodies are conſtituted by the union or contiguity of two or more tranſparent colourleſs media, differing conſiderably from each other in their reflective powers. Of theſe ſubſtances we have examples in frothy emulſions, or other imperfect combinations of pellucid liquors, as milk, ſnow, calcined or pulverized ſalts, glaſs or cryſtal reduced to powder, white earths, paper, linen, and even thoſe metals which are called white by mineralogiſts; for thoſe metals do not appear white unleſs their ſurfaces be rough; as in that caſe only there are interſtices on their ſurface ſufficient to admit the air, and thus make a reflection of a white and vivid light.

The poliſhed ſurfaces of metallic mirrors reflect the incident rays equably and regularly according to their ſeveral angles of incidence, ſo that the reflected rays do not interfere with each other, but remain ſeparate and unmixed, and therefore diſtinctly exhibit their ſeveral colours. Hence it is evident, that white ſurfaces cannot act upon the light as mirrors, becauſe all the rays which are reflected from them are blended in a diſorderly and promiſcuous manner.

The foregoing phenomena give us ſome inſight into the nature and cauſe of opacity, as they clearly ſhew, that even the rareſt tranſparent colourleſs ſubſtances, when their ſurfaces are adjacent to media differing greatly from them in refractive power, may thereby acquire a perfect opacity, and may aſſume a hue and reſplendence ſimilar to that of white metals; that the rarer pellucid ſubſtances cannot by the ſight be diſtinguiſhed from the denſe opake metals; and this ſimilarity to the ſurface of metals not only occurs, when from the roughneſs of their ſurfaces they reſemble poliſhed metals in whiteneſs, but alſo when from their ſmoothneſs they reſemble the poliſhed ſurface of metals.

Metals ſeem to conſiſt entirely of tranſparent matter, and to derive their apparent opacity and luſtre ſolely from the copious reflection of light from their ſurfaces. The analogy between metals and tranſparent media, as far as concerns their optical properties, will appear to you from the following conſiderations: 1. All metals diſſolved in their proper menſtrua are tranſparent. 2. By the union of two or more tranſparent media, ſubſtances are conſtituted which are ſimilar to metals in their opacity and luſtre, as plumbago and marcaſites. 3. The tranſparent ſubſtances of metals, as well as thoſe of minerals, by their union with inflammable matter, acquire the ſtrong reflective powers from which their luſtre and opacity ariſe. 4. The ſurfaces of pellucid media, ſuch as glaſs or water, aſſume a metallic appearance, when by their ſmoothneſs, difference of denſity with reſpect to the contiguous media, or any other, they are diſpoſed copiouſly to reflect the light.*

From theſe conſiderations it is evident, that opake ſubſtances are conſtituted by the union or contiguity of tranſparent colourleſs media, differing from one another in their reflective powers; and that when the common ſurface, which comes between ſuch media, is plane, equal, and ſmooth, it reflects the incident rays equally and regularly as a mirror; but when their ſurface is rough and unequal, or divided into minute particles, it reflects the incident rays irregularly and promiſcuouſly in different directions, and conſequently appears white.

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* For further particulars, &c. &c. ſee Mr. Delaval's paper, "Memoirs of the Mancheſter Society," vol. 2.

When the interſtitial vacuities of bodies are ſo diſpoſed, that the light can preſerve it's rectilinear courſe through them, ſuch bodies appear luminous throughout, and are viſible in their internal ſubſtance; but when their conſtitution is ſuch as will not allow a free paſſage to the light, they are then viſible only by thoſe rays which are reflected from their ſurface, and their internal ſurface is cold and dark.

From various conſiderations it appears, that the chemical properties of bodies have a conſiderable influence on their colour; for, doubtleſs, a force which acts powerfully in refracting the rays, muſt likewiſe influence their reflection; and it is hardly to be doubted but that the action of fire has a conſiderable ſhare in the production of colours; indeed it's ſhare in the operations of nature is ſo conſiderable, that it would be ſtrange if it ſhould be excluded from this more curious part.

By comparing the refractive power of different bodies, NEWTON found that inflammable ſubſtances poſſeſs it in a much greater degree than ſuch as are not inflammable. From his obſervations on this ſubject, he drew the wonderful concluſion,* that the *diamond* contained a large quantity of *inflammable* matter; that *water* was an intermediate ſubſtance between inflammable and uninflammable bodies, and that it ſupplied vegetables with the inflammable principle; which truths have been ſeen and demonſtrated only in the preſent day.

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* Berthollet's Art of Dyeing, p. 6.

Bodies, not tranſparent in their ordinary ſtate, may be rendered ſo either by relaxing their parts with heat, ſo that the light may paſs through them more eaſily, or by giving ſome new direction, together with an additional force, to the matter of light. Mr. Hawkſbee was very much ſurpriſed to find, that the ſealing-wax, and the pitch, within ſide a glaſs globe, became ſo tranſparent when the glaſs was whirled about and rubbed with the hand, that the fingers might be plainly ſeen on the other ſide through the coating. Oil is condenſed, when cold, into a ſort of globules impervious to the light; but when theſe globules are diſſolved, and opened by the action of fire, the oil not only becomes tranſparent, but appears as bright and ſhining as if the light were a natural part of it's ſubſtance.

Many heterogeneous fluids grow dark and muddy with cold, but may ſoon be clarified again by the application of a moderate heat: red-port wine is ſometimes as foul as if brick-duſt was mixed with it, but will ſoon become bright and clear before the fire.

The quality of tranſparency is given, by a wiſe ordination of Providence, to the fluid ſubſtance of water, which is ſo neceſſary to the life of all animals. Tranſparency renders glaſs moſt valuable; the value of gold is arbitrary, but the worth of glaſs is intrinſic; it's cleanlineſs and tranſparency recommend it to our uſe for the common purpoſes of life, and render viſible the moſt curious and ſubtil proceſſes of chemiſtry and philoſophy: in optics, it aſſiſts the aged, and gives to man an inſight into the wonders of creation. *

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* Jones's Phyſiological Diſquiſitions, p. 86.

LECTURE XXI.

OF PHOSPHORIC BODIES.

THE more the nature of light is inveſtigated, the more it's relation to fire is diſcovered: many proofs of this you have already ſeen, many more will occur in treating of phoſphoric bodies. As I have already ſhewn you, that fire is received and retained in bodies under the form of *heat*; I have now to ſhew you, that it is alſo retained in moſt ſubſtances under the form of *light*.

By phoſphorus we in general mean thoſe ſubſtances which ſhine in the dark, without emitting heat. Phoſphorus is divided into ſeveral kinds, known by the names of the *Bolognian* phoſphorus, *Mr. Canton*'s phoſphorus, *Baldwin*'s phoſphorus, phoſphorus of *urine*, &c. &c. Beſides theſe, it has been found that the far greater part of terreſtrial bodies, upon being expoſed to the light, will appear luminous in the dark. This circumſtance has occaſioned ſome writers to divide the phoſphori into two claſſes, namely, ſuch as require to be expoſed to the light either of the ſun or ſome artificial fire, before they become luminous; and ſuch as do not. Of the firſt kind are the Bolognian phoſphorus, Mr. Canton's phoſphorus, the phoſphorus from earths, &c.; of the latter kind are rotten wood, the ſkins of fiſhes, and the phoſphorus of urine. There is another claſs which becomes luminous by friction or vibration, as ſugar, and the ſolution of phoſphorus in ſpirits of wine.

It has been ſaid, "that philoſophy was never "under more obligation to what is called *chance*, "than with reſpect to the diſcovery of the pro"perty of imbibing of light, which was once "thought to be peculiar to a certain foſſil in the "neighbourhood of Bologna, but is now found in "many other ſubſtances. Not only was a *ſingle* and "leading fact, but a *whole ſeries* of facts the reſult "of caſual obſervation." You are, I hope, better learned, and will enter your proteſt againſt this opinion; for you know that ſuch an opinion, if embraced, would deprive you of that ſatisfaction of mind which ariſes from a ſtrong and well-grounded apprehenſion of a *Divine Providence*, and of your being conſtantly under a gracious protection that will guard you from every evil unproductive of greater advantage. It is indeed the main baſis of prudence and benevolence, as it enſures to you, that whatever you do well ſhall be attended with ſucceſs either at preſent or in futurity, and thus making the good of your fellow-creatures your own higheſt intereſt. As this opinion is thus dangerous, it can be no improper digreſſion to conſider it more attentively, and the more ſo as you will find another writer, to whom I ſhall have occaſion to refer you on the ſubject of phoſphorus, acknowledging that it was accident which lifted up the veil of nature to him, and attributing to the ſame blind cauſe the greateſt diſcoveries that have been made by others.

In common diſcourſe we often indeed ſpeak of *chance* or *fortune*, as a power influencing the affairs of men, and having a principal ſhare in the direction of all events; as frequently baffling the ſkill of the wiſe, the valour of the brave, and the ſtrength of the mighty; as turning the ſcale of victory, and determining the ſucceſs of all enterprizes. But if you examine the idea of chance philoſophically, you will ſee that it is neither agent nor power, nor has any other exiſtence except *in our own ignorance*; for whatever is aſcribed to chance or fortune, we ſhould ſee performed by other cauſes, if we had ſagacity to diſcern them.

Chance is *no cauſe* of any thing, and ſerves only to expreſs our *ignorance* or *uncertainty* of the manner in which other cauſes operate; and in this ſenſe may be applied to the moſt cogent neceſſity or moſt deliberate deſign, where we know not the tendency of the one, nor the purpoſe aimed at by the other. What is eſteemed more caſual than weather? Yet nobody doubts of the air being moved, the vapours rarified, and the clouds condenſed, according to a certain impulſe received from mechanical cauſes; but becauſe no mathematician nor naturaliſt can inveſtigate thoſe cauſes ſo as to calculate what they will produce, we ſay, the farmer depends upon chance to bring his corn to maturity, and give him a favourable ſeaſon for his harveſt: yet if we were acquainted with the reſpective qualities, and exact proportions, of the cauſes from whence they proceed, we might calculate the variations of the weather, as well as we now do the changes and eclipſes of the moon. So that an event, happening by chance, does not elude the operations of neceſſary cauſes, nor the acts of free agents, nor the proviſions of wiſdom; for the effects of all three will appear caſual when we cannot foreſee them. And when it is ſaid any thing is diſcovered by chance, or that fortune has had ſuch an influence upon our affairs, no more ſhould be underſtood by theſe expreſſions, than that we are ignorant of the cauſes acting around us, and affecting the ſucceſs of our meaſures. Before accident takes place in thoſe events where our agency has no concern, there muſt have been natural cauſes in motion previous to any thing thus appearing to fall out accidentally among them; and it is only our ignorance of their concurrence and powers that gives chance a title to the production.

Inventions, as we have on a former occaſion obſerved, may appear accidental, and ſo indeed they are with reſpect to us, for no man could have ſeen before hand the day when they would happen: but accidents ariſe from certain cauſes lying in train to produce them; when, and in what manner they ſhall come to paſs, muſt be referred to the DISPOSER of all events. It is frequent in philoſophical diſquiſitions, that the ſame inquiry produces very different diſcoveries. The attention paid to the immediate object of inveſtigation does not ſhut the eye of the obſerver againſt any thing elſe that may offer; and the ſtate into which the ſubject of examination is put, in order to favour an expected event, often gives origin to another not leſs intereſting.

Nature is nothing more than *a conveyancer*, whoſe channels we can in ſome meaſure trace, conducting activity from one ſubſtance to another; and chance grows like an excreſcence from the ſituation, the circumſtances, or mutual concurrence of other cauſes. We have no experience of any thing that can act otherwiſe than by tranſmitting an operation already begun. Volition is the only power, we know of, that is capable of beginning an action, or giving an impulſe it did not firſt receive. And whoever ſuppoſes a ſubſtance involuntarily ſelf-moving, or cauſing a new impulſe not in being before, builds upon a mere hypotheſis, without any fact, within the compaſs of his obſervation, to ſupport it; whereas, he who holds the contrary, does it becauſe experience of his own actions teaches him that he begins them himſelf, but that every thing acting involuntarily proceeds in another manner, only carrying on an operation begun by ſome other agent.

Our views of providence muſt be partial and imperfect at beſt, wherefore much of the wiſdom of God will appear fooliſhneſs to man; and ſo does wiſdom always appear to ſuch as have not capacity to diſcern the juſtneſs of her meaſures, nor the ends for which they were purſued: but the more attentively you obſerve the luminous tracts, you will find them ſpreading further and further into the dark and exceptionable, and they will open before you an ample field for contemplation. For you will diſcover wheel within wheel, be able to trace the connection between many of them, diſcern their exact adjuſtment to each other, and perceive one adapted to anſwer various purpoſes, till at laſt you will be ready to believe with PLATO, that the whole world is a tiſſue of cauſes and effects, wherein nearly or remotely every thing has an influence upon the reſt. From hence we may conclude, not only that the young ravens are fed, and the lilies of the field arrayed in the glory of Solomon by the DIVINE proviſion; but that of two ſparrows which are ſold for a farthing, not one of them falleth to the ground; not a hair is loſt of the number upon our heads; not an atom ſtirs without the permiſſion of our HEAVENLY FATHER.

Thus alſo GOD has been pleaſed by a long and extraordinary ſeries of events, continuing from the infancy of mankind, to nouriſh up a religion whereby purer ſentiments of himſelf, and a more extenſive charity, may be introduced among the vulgar; and has in his wiſdom raiſed up two trees, *philoſophy* and *religion*, from little ſeeds, and by ſlow and ſucceſſive gradations, whoſe influence when mutual continually tends to purify and *meliorate* mankind, but when ſet at too great a diſtance from each other, philoſophy becomes a vain babbler, and religion a ſuperſtitious enchantreſs. When properly mingled, their branches grow more vigorous, extend over a larger compaſs, and bear fruits of more general uſe, co-operating in that great deſign which has been carrying on from the earlieſt accounts of hiſtory by a remarkable courſe of providence, calculated for the benefit of the human race in general, diſtinct from that reſpecting particular perſons; intended to introduce a perfect rectitude of ſentiment both in the underſtanding, and inferior faculties of the mind.

Too numerous are the inſtances to be noticed in theſe Lectures, and they would lead me too far from the general plan of the work; but one or two I cannot refrain from mentioning. You know how much the art of printing has contributed to the advancement of learning; but this was not the diſcovery of any philoſopher; the world had been long acquainted with the method of ſtamping inſcriptions upon medals and ſeals, which one would think might naturally have led the ingenious to contrive how to ſtamp the pages of a book, yet was it never thought of until the appointed time written in the book of heaven.

The magnetic power of the load-ſtone was known 2000 years ago, but remained an object of idle curioſity for ages, until the uſe of the needle was diſcovered; when it opened to us a new world, gave a readier acceſs to the remoteſt regions of the old, became a means of communicating knowledge, and familiarizing the nations of the earth.

Gunpowder is ſaid to have been diſcovered by a monk trying experiments, without expectation of any ſuch reſult; but how greatly has it changed the polity of nations, and civilized the rugged manners of war, making it depend more upon ſcience than bodily ſtrength or perſonal courage, and uniting the civil with the military intereſt!

reſt! And in remote conſequence of theſe inventions concurring with other incidents in the amazing ſeries, mankind is become better united and civilized; every nation has ſome intercourſe with others, and the more barbarous gradually take a tincture from the more humane.

Let us now return to our phoſphoretic bodies, and firſt of the Bolognian phoſphorus. This was diſcovered about the year 1630, by Vincenzo Caſcariolo, a ſhoe-maker of Bologna, who being in queſt of ſome chemical ſecret, among other things tried a calcination of ſome ſtones to be found in the neighbourhood of that city; and obſerved, that whenever this ſtone was taken into the dark, after having been expoſed to the light, it was plainly viſible by a light iſſuing from itſelf, continuing to appear ſo for ſome time, when it became inviſible; but upon returning it to the light, and then carrying it back to it's former ſituation, it exhibited the ſame appearance as before.

Of bodies that give light in the dark there are ſeveral kinds; for ſome bodies throw out light *ſpontaneouſly*, and others upon being *excited*. Of the former kind ſome ſhine with a *natural light*, as glow-worms, dates, and a good many aquatics; others poſſeſs an *adventitious light*, as rotten woods, and the fleſh of ſome quadrupeds and birds. Theſe laſt are not naturally phoſphoric, but owe that property to ſome particular cauſe, which generally is *putrifaction*, and ſometimes an inſenſible change in the natural conſtitution of the parts.

Thoſe bodies which become phoſphori upon being *excited*, or whoſe phoſphoretic property is at leaſt aſſiſted by excitation, may be diſtributed into different ſpecies according to the mode in which this property is brought into action. Theſe modes are *attrition*, *agitation*, *heat*, *the free admiſſion of air*, and *being expoſed to the external light*.

Bodies of every kind become phoſphori by *attrition,* provided they can bear that force of friction which is ſufficient to produce the reluctant light that is hid in their ſubſtances; *agitation* agrees moſtly with liquid ſubſtances, as ſea-water.

The emerald phoſphorus, and many gems, and amongſt theſe not a few diamonds, the lapis lazuli, and a great part of the mountain cryſtals, become phoſphoric by the application of *heat.*

The free admiſſion of air not only produces light in uſing the phoſphorus of Konkel, but even a blaze of fire where friction is uſed. The phoſphorus of Homberg burns alſo furiouſly upon the approach of air.

The laſt claſs, thoſe which act after *being expoſed to the external light,* are exceeding numerous; there ſeem but two ſubſtances which do not emit light when tried in this way, except water, in it's fluid ſtate, and metals. All bodies then whatever, except water and metals, have a power of imbibing light, and when placed in proper circumſtances, of emitting it again.

This has been fully proved by the experiments of Mr. Beccari* of Bologna, and Mr. Wilſon, which have been made in the moſt ſatisfactory manner; indeed, ſo great has been their diligence, that there are but little hopes of adding any thing conſiderable to what they have done.

A very weak light can only be viſible in great darkneſs. When the ſun is in it's meridian ſplendor, the moon and ſtars are totally obſcured; and yet when his ſuperior light is withdrawn, how plainly the moon and ſtars appear. Art will produce a degree of darkneſs far exceeding that of the night, and in ſuch darkneſs the weakeſt light will become viſible. Mr. Wilſon, therefore, to judge of

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* Not Beccaria the electrician.

of the *illumination* of bodies, when brought from the light, made his experiments in a cloſet about 6 feet by 5 ½ feet, the height about 9 feet. It was painted black, or covered with black baize in every part, and had two doors which were 5 or 6 inches broader and longer than the ſpace to enter at. There were two curtains of black cloth over the hole where the hand was occaſionally put out, to expoſe bodies to the light; the outer one and inner one each conſiſted of three doubles: all theſe were conſiderably larger than the hole, which was about 15 inches diameter, and opened to the ſouth. There were ſmall leaden weights faſtened to the bottom of each curtain, to preſerve them in their places when the hand was drawn into the room; two curved pipes were fitted to the cloſet, one communicating with the external air from the top of the room, the other from the bottom, for the ſake of breathing freely; by means of this cloſet any ſubſtances could be eaſily expoſed to the light, or withdrawn from it.

Numerous, and well worthy of your attention, are the experiments made by *Wilſon* in this cloſet; here almoſt every ſubſtance was found to be phoſphoretic: but calcined oyſter-ſhells, and white paper, poſſeſſed this power in an eminent degree. A piece of paper with a key being expoſed to the light, and again taken into the room, the key was then removed, and there remained as much of the paper dark as had been covered by the key, leaving a black ſpace exactly of the ſame figure as the key. A gentleman's hand, and part of a ruffle, being dipped in the light, and then ſuddenly withdrawn, appeared luminous; and as every other part of the body was dark, it looked like a hand with a bit of ruffle ſuſpended in the air, ſo that the human body was found like others to be phoſphoric.

Though fluid water is incapable of emitting light, yet when condenſed into the form of ice or ſnow, it aſſumes it, like other ſpecies of matter. This accounts for the light afforded by ſnow lying on the ground, even when the heavens are involved in utter darkneſs; being expoſed to the light all the day, it abſorbs a great deal of light, and is thereby enabled to give out a conſiderable quantity in the night.

It is probable that all the bodies with which we are ſurrounded are ſufficiently endued with this phoſphoretic property, to enable animals to find their food in the night. To this it may be added, that the eyes of animals are better conſtructed for collecting light than the human eye: thus the ſubſtance ſpread out behind the retina of cats, owls, &c. is white, which reflects the moſt light; that behind the retina of gramenivorous animals is green; laſtly, that in the human eye is black; hence we require more light than animals to diſcover objects, but our viſion is more perfect.

From the foregoing experiments it appears, that the world is ſtocked with a variety of occaſional phoſphori, from which light is inſenſibly evaporating where we ſhould never have looked for it, nor could poſſibly have detected it, but for the ſubtle mode of examination contrived by Beccari and Wilſon.

OF CANTON'S PHOSPHORUS.

To prepare this, take ſome oyſter-ſhells, and calcine them, by keeping them in a good coal fire for half an hour; let the pureſt part of the calx be pulverized and ſifted; to three parts of this powder add one of the flowers of ſulphur, and mix them well together; put the mixture into a crucible, and ram it tightly therein; then let it be placed in the middle of a fire, where it muſt be kept red-hot for an hour at leaſt, and then ſet to cool. When it is cold, turn it out of the crucible, and cutting or breaking it to pieces, ſcrape off upon trial the brighteſt parts, which, if good, will form a white powder, which you may preſerve by keeping it in a dry phial, with a ground ſtopple.

The quantity of light which a little of this phoſphorus gives when firſt brought into a dark room, after it has been expoſed for a few ſeconds to the light of the day, is ſufficient to ſhew the hour by a watch, if the eyes have been previouſly ſhut for one or two minutes.

By this phoſphorus you may repreſent celeſtial objects, ſuch as Saturn and his ring, the phaſes of the moon, &c. If the figures of them made of wood, be wetted with the white of an egg, and then covered over with the phoſphorus, a flaſh from the diſcharge of an electrical jar will illuminate the phoſphorus as well as the light of the day.

By a variety of experiments made with this phoſphorus it appears, that when it had emitted all the light it could in the common ſtate of the atmoſphere, it would emit more on the application of heat, but that the ſame degree of heat would only render it luminous for a certain time.

Let one end of a bar of iron of about an inch ſquare, or a poker, be made red-hot, and laid horizontally in a darkened room, till, by cooling, it ceaſes to ſhine, or is barely viſible; then bring a little dry phoſphorus, which has been expoſed to the light, in a glaſs ball hermetically ſealed as near the hot iron as poſſible; and the phoſphorus, though inviſible before, will in a few ſeconds begin to ſhine, and will diſcharge it's light ſo very faſt, as to be entirely exhauſted thereof in leſs than a minute, and will ſhine no more by the ſame treatment till it has been again expoſed to the light. By this heat light received from a candle, or even from the moon, may be ſeen ſeveral days after; and phoſphorus that will afford no more light by the heat of boiling water, will ſhine again by the heat of hot iron. By means of this heat, phoſphorus, which had been kept in darkneſs more than ſix months, was found to give a conſiderable degree of light.

Mr. *Wilſon*, in his treatiſe on phoſphori, has made a variety of experiments on oyſter-ſhells calcined, and combined with nitrous acid, and without it; in all caſes they acquired the phoſphoric quality in a very high degree. He poured ſome aqua fortis, previouſly impregnated with copper, on a quantity of calcined oyſter-ſhells, ſo as to form them into a kind of paſte; this paſte was put into a crucible in a pretty hot fire, for about 40 minutes. Having taken out the maſs, and waited till it was cool, he preſented it to the external light; on bringing it back ſuddenly to the dark, he was ſurpriſed with the appearance of a variety of colours like thoſe of the rainbow, but much more vivid. In conſequence of this appearance of the priſmatic colours, he repeated the experiment in various ways; combining the calcined oyſter-ſhells with different metals, and metallic ſolutions; with the different acids, alkaline, and neutral ſalts; as well as with ſulphur, charcoal, and other inflammable ſubſtances; and by all of theſe, he produced phoſphori which emitted variouſly coloured light.

What is more remarkable, he found that oyſter-ſhells poſſeſſed the phoſphoretic quality, and would exhibit the priſmatic colours, in a ſurpriſing degree; and for this purpoſe nothing more was neceſſary than to put them in a good ſea-coal fire, and keep them there for ſome time. On ſcaling off the internal yellowiſh ſurface of each ſhell, they become excellent phoſphori, and exhibit the moſt beautiful and vivid colours.

From Mr. Wilſon's experiments it appears, that fire or inflammable matter is eſſentially neceſſary towards producing priſmatic colours in phoſphoric ſubſtances; that there is no particular diſpoſition in the ſhell to exhibit any particular colour without the aid and aſſiſtance of the inflammable principle; and that the ſeveral parts of the ſhells exhibit ſuch colours as correſpond with the different quantities of inflammable matter that they reſpectively contain.

The inflammable principle appears to be ſo weakly combined, that it is eaſily diſengaged in conſequence of the action of light.

Mr. Beccaria attempted to ſhew, that phoſphorus emitted the very ſame light that it received, and no other; and Dr. Prieſtley concluded from hence, that Zanotti was wrong in aſſerting, that phoſphori ſhine by their *own native light*, after they have been kindled by *foreign* light. Zanotti appears, from Mr. Wilſon's experiments, to have been conſiderably nearer the truth than Dr. P. apprehends; as he ſeems fully to have diſproved, by his numerous and accurate experiments, the opinion of Beccaria.

The experiments on phoſphori may perhaps be accounted for by conſidering, that as an heated iron, which is dark by day-light, appears red and fiery when carried into a dark room, having acquired but a part of that ignition which renders it luminous in the open day-light; ſo other bodies are capable of an *incipient ignition*, which is perceptible to the eye in artificial darkneſs; and it is this *incipient ignition* which brings them under the denomination of *phoſphori.* It is remarkable, that a degree of light is diſcernible in heated oil, when viewed in ſuch a dark medium; and that even cold water does not immediately extinguiſh the light imbibed by ſugar, gum, paper, &c.

It has long been obſerved, that bodies, when beginning to putrify, emit light: this has been obſerved in meat, fiſh, and particularly in wood; in meat the ſofteſt parts are moſt luminous, it looks, when in this ſtate, as if ſprinkled over with gems, and upon touching it the luminous particles come off on your fingers: this however does not take place before a certain degree of putrifaction is induced, and ceaſes after it has proceeded to a further degree.

The luminous appearance of the ſea has long been known, and variouſly accounted for; it now ſeems to be generally attributed to a phoſphoretic appearance, ariſing from putrified materials, from fiſh and vegetables, which riſe to the ſurface of the water in the form of ſcum, and when agitated yield more light than when at reſt.

There is a remarkable difference between the light of rotten wood, fiſhes, and that of phoſphorus of urine, even when it is not in an ignited ſtate; for this laſt does not ceaſe to be luminous even when included within an exhauſted receiver; the contrary of which happens to rotten wood and fiſhes. When kept in water, and placed in warm air, the phoſphorus of urine diſcharges ſuch large and bright flaſhes into the air above it, as are apt to ſurpriſe, and even to frighten thoſe who are unacquainted with it.

Phoſphori, in the moſt extenſive meaning of the word, may be conſidered as bodies giving light; though more properly they are thoſe bodies which give a faint light, (viſible only in the dark) upon being rubbed, or after having been expoſed to the influence of light.*

Bodies ſhine in the dark in conſequence of an exceſs in their heat, and by the emiſſion of this light the heat is in ſome degree diſſipated; the ſubſtance of the body is thus changed in it's temperature, or in relation to heat.

Bodies emit light alſo in conſequence of the reſolution of phlogiſtic matter, which had been contained in their ſubſtance or compoſition.

But bodies alſo emit light without being ſenſibly affected in their temperature, or having the compoſition of their ſubſtance changed; this change may be effected by that active principle, which there are many reaſons for ſuppoſing to reſide on the ſurfaces of bodies.

That particular ſpecies of bodies which have a peculiar power in their ſubſtance, by which incident light is reflected, or which have a power of abſorbing light, do not become phoſphoretic by having the powers of their ſurfaces excited by friction or incident light; but thoſe bodies which do not thus eminently abſorb or reflect light, and do not conduct electricity by their ſubſtance, are all in ſome degree phoſphoretic.

That the light emitted from the phoſphoretic body is not the identical light to which the body has been expoſed, is proved by Mr. WILSON's experiments. It would therefore appear, that the ſpecies of the emitted light ariſes only from the particular diſpoſition of the phoſphoretic body, and that by being thus properly diſpoſed, the ſame phoſphoretic bodies may, after being excited, emit any one particular ſpecies of coloured light, according to the manner in which it had been diſpoſed for this operation of producing light.

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* Hutton's "Diſſertations on different Subjects of Natural Philoſophy."

From the experiments of Mr. Wilſon it appears, that it is not the *exciting* light which is emitted by the body ſhining in the dark; it is not the *emitted* light, or light of the ſame ſpecies, which has the greateſt power of exciting the *phoſphorus* to ſhine; but the light which has ſo great an energy in exciting the phoſphorus, is that ſpecies of light which is placed at the other extremity of the priſmatic order, or moſt oppoſite in the rule of it's refrangibility from that of the emitted light.

Thus, though the incident light be a cauſe of ſhining by exciting this quality in the phoſphoretic body, yet there is interpoſed another operation between the incidence and the emiſſion of light; and there is reaſon to ſuppoſe, that the particular ſpecies of *light* emitted from the *phoſphoretic* ſurface, depends on the *electric* fluid put in action by the incident light.

Phoſphoretic and *phlogiſtic* bodies agree in containing a quantity of light, which is not in any perceived ſtate of heat.

Although phlogiſtic and phoſphoretic bodies emit light upon the ſame principles, ſo far as this depends upon luminous matter contained in the bodies, which is ſet at liberty during the operation, by which it is rendered luminous; yet the manner in which the luminous matter is ſet at liberty, is very different, as is that alſo by which the luminous matter is retained. The expoſure to the atmoſphere is eſſential to the emiſſion of light from *phlogiſtic* bodies; but this is a circumſtance indifferent or unneceſſary for the ſame operation in thoſe that are *phoſphoretic*. In *phoſphoretic* bodies there is no difference perceived after they have loſt their ſhining qualities; but this is not the caſe with *phlogiſtic* bodies, where the greateſt difference is perceived on the abſtraction of their luminous matter.

Phoſphoretic bodies furniſh us with a ſtrong additional proof of a principle already noticed, that *light* is matter which may continue for ſome time therein without exciting *heat*, and may be again ſeparated therefrom, and reſume it's character of light, as will appear by conſidering,

1ſt, That a phoſphoretic body is made luminous only by it's having been expoſed to light. 2dly, That it muſt be expoſed to light of a certain intenſity. 3dly, That provided the light falling upon the phoſphoretic body be ſufficiently intenſe, the moſt inſtantaneous expoſition ſuffices to ſaturate the body, ſo as to make it emit light viſible in the dark, equally as if it had been expoſed thereto for a longer time.

It follows from hence, that *light* is matter, and that this ſolar ſubſtance may be retained in connection with a body, either upon it's ſurface, or connected with the gravitating matter of which the body conſiſts.

GENERAL OBSERVATIONS CONCERNING SEVERAL OPERATIONS OF LIGHT IN RELATION TO BODIES. EXTRACTED FROM DR. HUTTON'S "DISSERTATIONS ON DIFFERENT SUBJECTS OF NATURAL PHILOSOPHY."

A body heated to an intenſe degree gives light, and light may be conſidered as matter moving in a ſtrait courſe directed from a body. It is a matter of general obſervation, confirmed by the experiments of Mr. Pictet, that the intenſity of heat in a body is diminiſhed in proportion to the light which is emitted from the body.

Light emitted from a hot body, and meeting in it's courſe with a colder body, whoſe temperature may be accurately meaſured, may be either reflected from the ſurface of the oppoſing body, or extinguiſhed within the ſubſtance of the body. In this laſt caſe, if, in proportion to the light extinguiſhed in the body, the intenſity of heat be increaſed, it may be concluded, that fire is moved from the body in light, but the intenſity of heat in a body is increaſed in proportion as light therein is extinguiſhed; it therefore is, as to matter, the ſame with fire.

Heat and light may thus be conſidered as different modifications of the ſame matter, or different actions, according to the ſeveral conditions in which that matter may be placed.

Light, which is incident in relation to a body, may be either reflected or tranſmitted, or both, and that in greateſt part. So far as light is reflected from the ſurface, or tranſmitted through the ſubſtance of a body, no heat ſhould be excited in conſequence of this modification of matter, which is not that of heat. This is conſiſtent with obſervation, for no heat is excited by reflected or tranſmitted light.

By *fire* the volume of bodies may be *changed*, by *light* the figure of bodies may be *perceived*; but we know not whether fire and light have a proper bodily form; yet their exiſtence is manifeſted by their effects; their actions, or laws of motion, are inferred or diſcerned by reaſon.

Nothing is more diſtinct than light and fire in their proper ſenſible qualities, but theſe ſenſible qualities are conditional. On the one hand, fire is not felt, if the ſenſitive body preſerves it's natural or proper quantity of this ſubſtance; on the other hand, light is not perceived when falling on the ſkin or hands. As the conditions therefore neceſſary to the productions of thoſe ſeveral ſenſations are perfectly different, from thoſe different ſenſations we cannot conclude the matter employed in both is not the ſame.

Bodies in relation to light are either *luminous* or *illuminated.* It is only by means of light that bodies become viſible, and this light muſt proceed from luminous bodies.

As bodies, by having the intenſity of their heat ſufficiently increaſed, may become luminous or made to emit light; if the light of bodies is conſidered in this moſt general view, the claſs of luminous bodies will be thereby greatly augmented.

In order to diſtinguiſh bodies that are *properly luminous* from thoſe that *only emit light in conſequence of heat*, it will be proper to obſerve, that bodies emitting light in this laſt manner, are not changed further than neceſſarily follows from the operation by which the proper degree of heat is produced; conſequently theſe bodies may return to their former ſtate, and, by being again heated, may have theſe operations repeated without limitation. But bodies properly luminous are limited in the quantity of light which they had retained, and which they are able to emit; after which thoſe bodies, exhauſted of their proper light, can only be luminous, in conſequence of fire acting as heat.

Bodies that are eminently luminous muſt emit a quantity of light which had been contained in them; ſuch bodies muſt therefore contain a certain ſpecies of matter in their ſubſtance, and this is called *phlogiſtic inflammable* or *combuſtible* matter. Now this phlogiſton may in the chemical operations of matter be tranſlated from the ſubſtance of one body to another; by which means bodies are made phlogiſtic, or capable of becoming eminently luminous, that were not ſo before.

All bodies that are made to give light require a certain degree of heat, without which they will remain without giving light; ſo that all bodies that are to emit light, whether properly luminous or not, agree in having the emiſſion of light as a conſequence of heat, and in requiring a certain intenſity of heat as a neceſſary condition for the emiſſion of light: ſo far as this is the caſe, without heat bodies could not give light.

Heated bodies emitting light, I have already obſerved, are thereby continually loſing heat, while colder bodies expoſed to light, are receiving heat; ſuch bodies therefore muſt have both their heat and light continually diminiſhed, by forming an equilibrium of heat with contiguous and ſurrounding bodies.

It is otherwiſe with combuſtible bodies, for though theſe require a certain degree of heat as a condition of their emitting light; yet, as they alſo emit light upon other principles, ſo during their emiſſion of light, appearances take place very different from thoſe of bodies that are only luminous by the intenſity of their heat.

The ſolar ſubſtance appears to be variouſly modified in relation to bodies, or differently diſpoſed with regard to ſpace and things; it is in one place *fire*, in another *light*, in a third *electricity*. In each of theſe modifications there are properly perceived actions with different intentions, but not oppoſite natures. From various ſimilitudes, the ſeveral actions are concluded as belonging to the ſame kind of matter, from the ſeparate purpoſes perceived in their various diſtinguiſhed or different modifications.

Bodies, in relation to light, may be diſtinguiſhed as of two different kinds; one kind giving light of their own, or which had been part of their ſubſtance, immediately before the act of emiſſion; the other kind giving no light, except that with which they are illuminated from other bodies. Hence a general diſtinction of bodies, ſome being luminous, others dark or opake.

Bodies, in relation to that light with which they are illuminated, are conſidered as of two kinds, either tranſparent or opake. Here is therefore another ſenſe, in which opacity may be taken; conſequently, before the various affections of light and bodies are examined, it will be proper to have a diſtinct notion of this quality, which may perhaps be conſidered in different ſenſes.

Opacity, as a quality in bodies, may be conſidered either in a more limited or in a more extenſive ſenſe; in the one caſe it ſignifies want of tranſparency, in the other that no light comes from a body. The firſt is a quality, properly or only oppoſed to tranſparency; the laſt will ſignify darkneſs in a body, from whatever cauſe.

Opacity being conſidered in the moſt extenſive ſenſe, then, as there are two different principles of lumination or modes by which light may proceed from a body, the quality of opacity may be examined in relation to each.

Light properly belonging to a body, being emitted, is ſaid to come from a luminous body; therefore opacity in being applied to a body, may mean a body that emits no light of it's own. But as, in this caſe, the light to be emitted is ſuppoſed to be part of the body, or it's ſubſtance's opacity, in this particular ſenſe, will mean a quality only in relation to the ſubſtance of the body, and not to it's form, that is, to it's figure and volume.

At the ſame time that this quality of opacity is thus found to be applicable only to the ſubſtance of a body, it muſt alſo appear that this is only a negative quality, meaning that the body has no light of it's own to emit; or, if it does contain luminous matter, that there are not proper conditions for the emiſſion of that ſubſtance.

With regard to the other mode of giving light, when a body may have opacity, or ſhall be conſidered as opake, this relates to incident or foreign light. Light falling on a body may be either reflected, in which caſe it illuminates the body, or it may be tranſmitted, in which caſe the body is tranſparent; in neither of thoſe two caſes, is opacity, as a quality, neceſſarily perceived in that body. But light entering the ſurface of the body, and being there retained without immediate emiſſion, here is to be perceived a quality in the body, which, at the ſame time that it is a poſitive quality, is alſo properly ſpeaking the quality of opacity, as being oppoſed to the tranſmiſſion of light, which is tranſparency.

In this caſe of opacity, conſidered as a poſitive quality, no relation is to be perceived between form, figure, or volume, the proper qualities of a body, and this quality or power in relation to light; therefore, opacity, in this moſt proper ſenſe, muſt be conſidered as a quality, which, whilſt it is poſitive, belongs only to the ſubſtance of the body, and may be properly examined without attending to the form or volume.

Tranſparency conſiſting in the free tranſmiſſion of light through a body, the abſolute ſolidity of the particles of matter in a body muſt be inconſiſtent with that quality; for, as tranſparent bodies tranſmit light equally in all directions, it is only by ſuppoſing the reſiſting parts of the body to be to the unreſiſting parts, in a ratio leſs than any aſſignable proportion, that this quality of perfect tranſparency can be thought conſiſtent with the extenſion, and direct motion of the rays of light. At the ſame time, in judging from the hardneſs and incompreſſibility, if theſe are ſuppoſed to depend upon the ſolidity of the ſubſtance, there muſt be a great proportion of matter in the body.

But as there is no reaſon to doubt of the perfect tranſparency of bodies, conſidered ſolely as a tranſmitting quality, there is perhaps every reaſon that can be drawn from the concurring teſtimony of natural appearances, to juſtify the ſuppoſition, that, in a tranſparent body, the abſolute volume of matter, neceſſarily oppoſing the paſſage of light, and the abſolute volume of the parts of light that muſt neceſſarily be oppoſed in paſſing through that body, are, to the reſt of the ſpace, in a ratio leſs than any aſſignable proportion. This being the caſe, it muſt be evident, that thoſe two qualities of tranſparency in relation to the rays of light, and reſiſting power in relation to external force, are things plainly inconſiſtent, if we are to ſuppoſe ſolid matter to be the principal of bodies.

On the other hand, opacity, conſidered as a quality by which tranſmiſſion through the ſubſtance of a body is refuſed, will appear not to ariſe from the neceſſary reſiſtance of the matter in a body to the rays of light from it's extenſion, nor from the mechanical diſpoſition of that matter in any conceivable manner; for, 1ſt, According to any way of forming a judgment, with regard to the quantity of matter in a body, that quantity does not appear to have any influence in producing opacity.

2dly, The ſmalleſt examinable quantity of matter, ſufficiently opake, appears to be as effectual to interrupt the paſſage of light, as the greateſt quantity of matter not ſufficiently opake; at the ſame time this quality of opacity in a body, does not appear to be altered by any mechanical change or diſpoſition of the parts: therefore, though the tranſparency of bodies were explicable from the ſuppoſition of infinite ſtrength, and infinite rarity, in the ſolid matter and conſtruction of bodies, this theory or ſuppoſition would ſtill be inconſiſtent with the oppoſite quality, that is, opacity in bodies; for, while the greateſt quantity of a denſe tranſparent ſubſtance tranſmits light perfectly in every poſſible direction, the ſmalleſt quantity of a rare opake ſubſtance ſuffices to arreſt light or retain it, without reflection or tranſmiſſion. It is thus impoſſible, upon mechanical principles, to reconcile thoſe two different qualities of bodies; therefore, independent of the inſurmountable difficulty of conſtructing the ſolid matter of bodies for thoſe two oppoſite purpoſes, here is a demonſtration, from the ſimple quantities of the matter in bodies, by which it is proved, that opacity does not ariſe from any mechanical conſtruction of ſolid matter; and therefore, that bodies are not compoſed of ſolid matter and ſpace, ſeparate and contiguous.

Light appears to paſs through the ſubſtance of a homogeneous tranſparent body with equal facility, as it is conceived to move in the *rareſt* or *voideſt* ſpace; conſequently, the matter of ſuch a body makes no ſenſible reſiſtance to light. Therefore it may be inquired, what kind of matter is this, that has not the power of reſiſting light? Or, what particular powers in bodies are aſſociated with this deficiency of power in relation to light?

The *hardeſt* and *ſofteſt* bodies are equally tranſparent; light does not appear to be tranſmitted through a *diamond* with leſs facility than through the *air:* therefore, that power in bodies, which reſiſts the motion of the parts in relation to each other with ſo great intenſity, does not reſiſt the motion of light, or this particular modification of matter.

Fluid and *concreted* bodies, *water* and *cryſtal*, are equally tranſparent; conſequently, that power by which the parts of bodies are directed to particular ſituations, does not interpoſe any reſiſtance to the paſſage of light.

Heavy bodies may be tranſparent, as well as *lighter* bodies; *glaſs of lead, cryſtal, ice, air*, are all tranſparent bodies; therefore, as the matter of light appears to have no gravitating power, the power of gravitation in bodies makes no oppoſition or reſiſtance to the motion of light.

The *particular attractive powers* of ſubſtances appear to be no more diſpoſed to reſiſt the matter of light, than the general powers of bodies which have been conſidered; thus air, water, acid, alkali, and neutrals, are all tranſparent.

Therefore, from the examination of bodies with regard to tranſparency, this general concluſion may be formed, that the *attractive gravitating matter* in bodies appears to have no power calculated to oppoſe and reſiſt light.

But in opake bodies, there are powers by which light is effectually reſiſted.

In the tranſparent bodies already examined, every ſpecies of ſubſtance has been conſidered, except one; and this, which is *phlogiſtic* ſubſtance, not yet examined with regard to light, has been found capable of oppoſing, reſiſting, and changing every general attractive or gravitating power in bodies: therefore, on finding this ſubſtance properly adapted, whether in a mediate or immediate manner, for the oppoſition, reſiſtance, and change of light, the qualities of tranſparency and opacity in bodies will be properly explained; at the ſame time that this natural appearance of tranſparent and opake bodies being in perfect conſiſtency with the theory of matter already inveſtigated, will add that confirmation which in phyſical ſubjects is required.

Tranſparent bodies have been conſidered as not affecting the light, which thus traverſes their ſubſtance with perfect facility; but it is a neceſſary condition for this purpoſe, that the ſubſtance be homogeneous, and equal in it's denſity, or, that the body be ſufficiently uniform in relation to the volume occupied by it's ſeveral parts; for a greater degree of denſity in one part of a body, otherwiſe perfectly homogeneous, diſpoſes the body to affect the light in that part where the change of denſity takes place.

Hence the ſurfaces of contiguous bodies, which are tranſparent, but of different denſities, are obſerved to affect light in different ways, and according to a certain rule.

Thus reflection, refraction, and extinction, are affections of light by tranſparent bodies, the rule or laws of which, to the honour of philoſophy, have been ſo well inveſtigated.

From the particular laws obſerved in thoſe caſes, there is reaſon to conclude, that there are certain powers ſituated in a place correſponding to the ſurfaces of bodies, by which light, that otherwiſe would be unaffected, may be both deflected in it's courſe, and arreſted in it's motion. But on conſidering electricity, there are found certain powers ſituated preciſely in this place; and, as the matter of electricity, which is properly ſituated in this place, and that proper to phlogiſtic ſubſtance by which alone light has appeared to be affected, are of the ſame kind, being different modifications of the ſame ſpecies of matter, there is reaſon to conclude, that the powers by which light is affected at the ſurfaces of tranſparent bodies, are of the ſame nature with thoſe by which, in opake bodies, light is alſo found to be affected.

OF THE INFLECTIONS OF THE RAYS OF LIGHT WHICH PASS IN THE VICINITIES OF BODIES.

THE experiments on this ſubject by Sir I. Newton were the laſt that he made, and are acknowledged by himſelf to be incomplete; thoſe who have followed him in this delicate and important department of natural philoſophy, have done little more than added ſome inſulated facts to thoſe obſerved by him. The law followed by the powers that inflect the light, and the limits of it's action, are yet unknown. One, however, of the general reſults from the experiments is, *that bodies act upon light at ſmall diſtances by attraction and repulſion.*

If a beam of the ſun's light be admitted into a darkened chamber, through a hole of the breadth of a forty-ſecondth part of an inch or thereabouts, the ſhadows of hairs, threads, pins, ſtraws, &c. appear conſiderably larger than they would be if the light paſſed by them in ſtrait lines. For example, a hair whoſe breadth was the 280th part of an inch being held in this light, at about 12 feet from the hole, caſt a ſhadow, which at the diſtance of 4 inches from the hair was the 60th part of an inch broad, that is, above four times the breadth of the hair. And the effect is the ſame, though the denſity of the medium contiguous to the ſmall body be altered, the ſhadow at like diſtances being equal, whether it was in the open air, or incloſed between two plates of wet glaſs, care being taken that the incidence and emergence of the ray was perpendicular to the glaſſes. The ſcratches on the ſurface, or veins in the glaſs, caſt ſhadows broader than they ought to be, from the uſual refraction which might ariſe from any action of the ambient medium.

Let x, *fig.* 2, *pl.* 7, be a hair placed in the beam; A D G, B E H, K N Q, L O R, rays of light paſſing by the ſides of it, are bent at x, and falling upon the paper G Q, the two rays T I, V S, paſs by the hair without being deflected; but all the rays between T I and V S are bent in paſſing by the hair, and turned aſide from the ſhadow I S. The light paſſing neareſt the hair, as at D and N, is moſt bent paſſing to G and Q; thoſe that are farther off, as at E and O, are leſs bent; and ſo on to T I and V S: conſequently the action upon the rays of light is ſtrongeſt at the leaſt diſtances, and grows weaker and weaker as the diſtance of the ray paſſing by is increaſed.

The ſhadows of all bodies in this light are bordered with three parallel fringes of coloured light; the neareſt to the ſhadow is the brighteſt, and the furtheſt very faint; the order of the colours, reckoning from the innermoſt, are violet, blue, green, yellow, red. On looking at the ſun through a feather or black ribbon, held cloſe to the eye, ſeveral fringes of colours will appear.

Let a beam of the ſun's light be admitted through a hole $\frac{1}{4}$ of an inch broad; place a ſheet of paſteboard, blacked on both ſides, at about 3 feet from the hole; in the middle of the paſteboard let there be a hole $\frac{1}{4}$ of an inch ſquare for the light to paſs through; behind the paſteboard faſten the blade of a ſharp knife, ſo as to ſtop part of the light going through the hole. The knife and paſteboard are to be parallel, and both to be at right angles to the beam. Let a part of the light, which paſſes by the knife edge, fall upon a white paper at about 3 feet diſtance, and there will be two ſtreams of light ſhooting out both ways into the ſhadow, ſomewhat like the tails of comets.

Theſe ſtreams being very faint, it is neceſſary, in order to ſee them diſtinctly, to let the direct rays paſs through a hole in the paper on a piece of black cloth; the light of the ſtreams is then perceptible on the paper to the diſtance of 6 or 8 inches from the ſun's direct light each way, and in all the progreſs from that direct light decreaſes gradually till it becomes inſenſible.

Placing another knife with it's edge very near and parallel to the firſt, if they be diſtant the 400th part of an inch, the ſtream of light paſſing between them will be divided, parting in the middle, leaving a dark ſhadow in the interval: as the edges approach, the ſhadow grows broader, and the ſtream narrower at the inner end: ſo that the light that is leaſt bent goes to the inner end of the ſtream, and paſſes at the greateſt diſtance from the edges. This diſtance is about the 800th part of an inch; when the ſhadow begins firſt, the light which paſſes at leſs diſtances is more bent, and goes to that ſide which is fartheſt from the direct light; a little before the ſhadows appear, the fringes commence on both ſides, and as the knives approach they grow more diſtinct and larger, till upon contact of the knives, the whole light vaniſhes, leaving it's place to the ſhadow.

Admit a beam of the ſun's light through a ſmall hole, made by a pin, in a thin plate of lead, and place a priſm at the hole to refract the light on the oppoſite wall. The ſhadows of all bodies held in the coloured light are borderd with fringes of the colour of that light in which they are held; in the red, they are red; in the blue, blue, &c. but the fringes in the red light, are the largeſt; thoſe in the violet, leaſt; the green, between both; and this at all diſtances from the ſmall body.

So that the rays which made the fringes in the red light, paſſed by the hair at a greater diſtance

tance than thoſe which made the violet fringes; conſequently the hair in cauſing theſe fringes acted ſimilarly upon the red rays, which were at a greater diſtance, as upon the violet at leſs diſtances; and by theſe actions diſpoſed the red light into larger fringes, and the violet into ſmaller, &c. without changing the colour of the rays.

When a hair is held in a white beam of ſolar light, and caſts a ſhadow which is bordered by three fringes of coloured light, theſe colours ariſe from the various inflections by which the rays are ſeparated, and being ſeparated produce each it's own colour. In the laſt experiment, where the rays are ſeparated before the light comes to the hair, the red or leaſt refrangible rays were inflected at greater diſtances, and the violet or moſt refrangible rays at a leſs diſtance, making three violet fringes at a leſs diſtance, whilſt the red makes three red fringes at a greater diſtance; the mean rays making 3. fringes of their proper colours at mean diſtances from the ſhadow of the hair. In the white light theſe various colours are ſeparated by the various inflection of the rays, and their fringes appear all together; the innermoſt being contiguous, make one broad fringe, compoſed of all the colours in due order, the violet being next the ſhadow, and the red fartheſt off, and the reſt in their places. In like manner the middlemoſt fringes conſtitute one broad fringe, of all their colours, and the outmoſt fringe compoſe another broad fringe like the reſt; and theſe are the three fringes of coloured light with which the ſhadows of all bodies are bordered.

From theſe and ſome other experiments of the ſame tendency, it may be inferred that the rays of light are influenced by ſome power that turns them out of their direct road; and as this power bends the rays not into the ſhadow of the bodies from whence the influence is ſuppoſed to proceed, but from the ſhadow, it has been conſidered as a repulſive power which is ſtrongeſt at the leaſt diſtance.

OF THE ACTION OF LIGHT ON BODIES, AND THAT THE COLOUR OF PLANTS, &c. DEPENDS ON LIGHT.

You will often find, that philoſophical knowledge makes quicker advances by reaſoning upon known facts, than by diſcovering new ones, which, though they enlarge and add to the ſubjects we ought to reaſon upon, are apt by their novelty to ſurpriſe us into haſty undigeſted theories. We have a ſtrange propenſity to be looking either behind or before us for variety, inſtead of cultivating the fruitful ſpot we ſtand upon. I am led to make this and ſome of the following obſervations from the ſubject before us, which has been too much neglected by modern philoſophers: we have treatiſes on light, as ſeparated and divided by the priſm; on heat, as meaſured by the thermometer; but none on that ocean of the ſolar fluid, in which all bodies are as it were immerſed;* none upon the various influences of the ſun, upon which the life and activity of all things in this natural world depend. They ſeem to have forgotten, that the proceſſes continually carrying on in nature, on every ſide, are as much the inſtruments of knowledge, as the more refined apparatus of the experimental philoſopher. Senſe and experience acquaint us with the courſe and analogy of appearances or natural effects; thought, reaſon, intellect, introduce us into the knowledge of their cauſes.

To avoid the conjectural method of ſome former philoſophers, thoſe of the preſent day are continually labouring to accumulate unconnected facts; thinking every new form, or every new appearance,

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* Young's Eſſay on the Power and Mechaniſm of Nature.

pearance, an important diſcovery; ſeldom endeavouring to trace out their connection with ſuperior and inferior cauſes, on which all their real powers and activities depend. If we ſtop at experiments, without proceeding any further, we ſhall never arrive at any cauſes; and if we rely wholly upon experiment, we ſhall come at none but falſe ones; becauſe the principal agent in nature is ſo ſubtil as to elude both ſenſe and experiment, ſo that they can never diſcover it, though when we have been told of it they will ſerve to demonſtrate it's obſervations.

The ancients paid little attention to experimental philoſophy, but devoted themſelves, with a truly philoſophical ardour, to the obſervation of the phenomena of nature; and that proceſs was conſonant to ſound reaſon, for experiment is only properly called in to fill up the chaſm which ſimple obſervation neceſſarily leaves.

The department of experimental philoſophy is the unfolding of thoſe phenomena, whoſe cauſes cannot be diſcovered by unaſſiſted reaſon, and whoſe connection it cannot trace; the advancement therefore of this branch of ſcience depends on the number and accuracy of our obſervations with reſpect to the relations which natural objects have to each other.

It has been well obſerved by Dr. G. Fordyce,* that "all our knowledge of every thing whatever muſt ariſe from experiment only, that is, from the evidence our ſenſes give us of what appearances nature, in other words, the creatures of the Almighty, give impreſſions of." Yet "ſome of theſe impreſſions are received from the ideas that ariſe from things not at all under our dominion, or from circumſtances more immediately governed by the Almighty. Thus, for example, a man ſees a tree loſe it's leaves in autumn, ſees them renewed in ſpring, and a new growth takes place during the ſummer; he ſees the bloſſoms open in the ſpring; theſe he finds followed by the fruit, which, if it falls into the earth, is capable of producing new trees of the ſame ſpecies; or he ſees it gathered by animals, and affording nouriſhment. In this *mode* of acquiring knowledge man is totally *paſſive;* he did not contrive to make leaves fall in the autumn, and be reproduced in ſpring; he did not contrive to make new wood grow in the ſummer, nor that bloſſoms ſhould open, that the ſeeds ſhould be impregnated with the embryo; he did not contrive that the fruit ſhould grow, nor did he teach animals that it was fit for their nouriſhment. What knowledge is acquired by attention to theſe natural circumſtances, has been called *obſervation.* It is indeed a contemplation of the *benevolence* of the ALMIGHTY, giving nouriſhment and happineſs to all the inhabitants of the earth.

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* Fordyce on the Digeſtion of Food.

"The minds of mankind, not ſatisfied with their powers of obſervation of what paſſes in this earth, but being even forced for their own ſubſiſtence to exert themſelves far beyond the brute creation, are neceſſarily led to make a farther inquiry, and that with a labour beyond the contemplation of the benevolence of the Almighty. To thoſe creatures who have only this earth to exiſt in, food and raiment are afforded, without labour or attention, during the ſhort period of their lives. It is not ſufficient for the farmer to look where grain grows naturally; it is neceſſary to try, with an infinite variety of applications that may be made to the ground, to produce crops ſuperior to thoſe which would ariſe in it without any cultivation. It is neceſſary for the hunter not only to obſerve the natural hiſtory of wild beaſts, but alſo to try by what means he can engage them to fall into his toils. It is neceſſary for the fiſherman, beſides admiring the multiplicity of fiſh, to be able to contrive either to entangle or ſurpriſe them into his nets. In many other caſes it is neceſſary for mankind not only to contemplate thoſe things which happen naturally, but he is likewiſe conſtrained to form projects of his own, and to contrive means of putting both mind and matter in circumſtances foreign to what would naturally ariſe in them, and contemplate the effects; and this we call experiment.

"Thus obſervation and experiment are the ſources of all the knowledge of mankind.

"Man ſeems to have a degree of pride planted in his nature, which prompts him conſtantly to conſider himſelf as being far ſuperior to what he actually is, which inſtinct is the ſureſt proof that *he is to be very ſuperior indeed.** But as all the virtues of man are ballanced by oppoſite imperfections, the pride of experiment has often thrown ſcience into confuſion, inſtead of advancing it's progreſs. An experiment to prove a thing otherwiſe demonſtrable is totally ſuperfluous, and not only ſuperfluous but fallacious."

Another circumſtance which injures philoſophical purſuits, and retards their progreſs, is the neglect of old principles as ſoon as new ones are aſſumed, as if their efficiency ceaſed immediately, like that of old miniſters of ſtate upon the introducing of new ones. If the placita of their predeceſſors were not loſt ſight of or neglected, they would ſooner attain the end of their inquiries, than by being ſo intent on their own diſcoveries as to neglect, as rubbiſh, all thoſe circumſtances that were formerly of ſuch moment.

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* Every vanity of man ſhews his degraded ſtate, and from what dignity he has fallen. Did not man find and feel that he is a poor priſoner in the valley and ſhadow of death, he would no more have any of thoſe inſtincts alluded to above, nor any reaching deſire after all the beauties of fallen nature, than the *ox* to have his paſture incloſed with beautiful walls and painted gates.

That light and fire are ſubſtantially the ſame, or different modifications of the ſame fluid, is evident from their commutability, or their reciprocal generation of each other. For as fire neceſſarily generates light, and thus diſcovers itſelf to the ſenſe of ſeeing as infallibly as to the feeling; ſo light conveyed to a focus, conſtitutes pure fire. Light and heat are propagated by the ſame laws; they act in ſtrait lines; they diffuſe themſelves from a center outward; their powers decay according to their diſtances from the centers from which they are irradiated; they are ſubject to the ſame laws of reflection.

Notwithſtanding that the phenomena of nature, which tend to aſcertain beyond doubt that the matter of common light or fire pervades all nature and fills all things, are exceeding numerous and obvious to every eye; yet the whole has been overlooked as an accidental filtration, implying no conſequences, nor interfering with the various properties of bodies, notwithſtanding it's acceſs to their innermoſt penetralia.

Our globe itſelf ſeems to be nothing more than an accumulation of terreſtrial materials, introduced into the boundleſs ocean of the ſolar fluid, for a theatre on which it may diſplay it's inexhauſtible power and energy; the maſs being ſo diſpoſed and arranged by it's author as to become a ſeminal bed of materials, to be pierced and animated by *light*, and from which materials light can extricate all the forms, and generate all the powers in nature.

Without this principle all that we call body would remain for ever an inactive, paſſive, incoherent calx. Water by it's tranſparency evidences to your ſenſes, that light has free acceſs into and through it's ſubſtance. By the volatilization of water it is equally evident, that light or fire has not only acceſs to it's interſtices, but penetrates and occupies it's ſimilar elementary particles, in the conformation of which particles the character of water conſiſts. Theſe particles could not be rendered volatile but by internal dilatation, nor could they be dilated but by ſomething that reached their internal parts; they have their individuality as ſeparable elementary particles, as well as their ſimilarity of character preſerved by the ætherial principle poſſeſſing them. If the natural life of all things depends on the activity communicated to them by the ſun, is it not evident that it is the ſame influence which muſt generate and maintain that life in all it's ſpecific characters, in every being according to it's kind?

When the *ſun* is ſaid to *rule* over the day, and to have been made for this end, what elſe can be underſtood but that he acts as a vicegerent; and is inveſted with a mechanical power of giving light, life, and motion, to ſuch objects as are ordained to receive his impreſſions? All nature revives, and puts on a new face, when he approaches us in ſpring; and ſinks into a temporary death, at his departure from us in the winter. That he acts in a mechanical manner, is alſo certain, becauſe a chain of matter is continued all the way from the agent to the object. His power conſiſts not in any immaterial quality, becauſe it obſerves the ſame geometrical law with the diffuſion of it's light; and his efficacy upon the production of the earth is greateſt, when the greateſt angle is formed between the horizon and his *rays*. A good teleſcope will ſhew you what changes are produced in the refraction of the atmoſphere, and what a tumult ariſes in the air from the agitation of the ſunbeams in the heat of noon-day; the heaven ſeems tranſparent and undiſturbed to the naked eye, while a ſtorm is raiſed in the air by the impulſe of light, not unlike what is raiſed in the waters of the ſea by the impetuoſity of the wind. It increaſes with the altitude of the ſun; and when the evening comes on, it ſubſides almoſt into a calm.*

Light is now no longer conſidered by chemiſts,† merely as an ideal ſubſtance; they perceive it's influence in many of their operations, and as it modifies many of their reſults, they find it neceſſary to attend to it's action.

The effects of light are more evident in the phenomena of nature, than in the experiments performed in the laboratory.

Light is abſolutely neceſſary to plants; vegetation does not ſucceed without it; deprived of this principle, they become pale, languiſh, and die. It appears from inconteſtible facts, that the root of the moſt variegated flower, though excluded from the external air under a glaſs veſſel, will, provided it be daily expoſed to the light of the ſun, arrive at it's utmoſt perfection both with reſpect to fragrance and colour; but if the proceſs be reverſed, and the air admitted without the light, the flower may perhaps grow to it's natural ſize, but we ſhall in vain look for that beautiful variety of vivid colouring, and that exquiſite perfume which nature beſtows on every individual of the ſpecies, when permitted to imbibe and enjoy the ſolar beam.

The ſame fact is further evinced by a variety of experiments by ſeveral French academicians, in which the light was admitted to one part of a plant, and excluded from the others. The invariable effect of this was, that the part expoſed to the ſun was of a lively green, while that which was ſhaded continued of a diſagreeable pale colour; nay, ſo powerful are the effects of the ſun's light on vegetables, that when deprived of it, their taſte and other native properties undergo ſuch a change, that ſome, in their nature poiſonous, become a ſafe and wholeſome food. Without the influence of light, vegetables would exhibit one lifeleſs colour, and are deprived of their beautiful ſhades by the interception of the luminary fluid. On theſe principles, celery, endive, and other plants, are *bleached.*

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* Chaptal's Elements of Chemiſtry.

† Jones's Eſſay on the Firſt Principles of Philoſophy.
—— Phyſiological Diſquiſitions.

All theſe circumſtances evidently ſhew, that there is ſomething in light abſolutely neceſſary to vegetable life. Hence all plants ſhew a remarkable ſenſibility to the light; they expand their leaves, and open their flowers to the ſun, and cloſe them the moment he diſappears. Many accurate experiments prove, that it is not the heat but the light of the ſun, that cauſes them to turn to him. A plant in a room, where there is a fire, turns it's flowers to the light which comes from the colder ſide.

Many experiments ſhew, that the change of poſition in the leaves of plants, at different periods of the day and night, is entirely owing to the agency of light. The upper ſurface of leaves, which are ſuppoſed to be their organ of reſpiration, ſeems to require *light* as well as *air;* for plants, which grow in windows on the inſide of houſes, are as it were ſolicitous to turn the upper ſides of their leaves to the light. This agent is ſubtil, active, and penetrating; by the ſmallneſs of it's conſtituent particles, it is capable of entering all bodies, and from it's activity of producing great effects and conſiderable changes therein.

Vegetables are not only indebted to the light for their colours, but likewiſe for their ſmell, taſte, combuſtibility, maturity, and the reſinous principle, which equally depend upon this fluid.* The aromatic ſubſtances, reſins, and volatile oil, are the inheritance of ſouthern climates, where the light is more pure, conſtant, and intenſe. All theſe circumſtances, it is hoped, will concur to make you attentive to the nature and office of the *ſun.* The ſun is *the united power* of fire and light, and by theſe powers calls forth from the earth a beautiful variety of vegetable life, cloathing them with it's own brightneſs and beauty, and rendering them holders and diſplayers of all it's colours, powers, and virtues.

The influence of light is evident on other animated beings: worms and grubs, which live in the earth or in wood, are of a whitiſh colour. Birds, and flying inſects of the night, are likewiſe diſtinguiſhable from thoſe of the day by the want of brilliancy in colouring; and the difference is ſtill more marked between thoſe of the north and of the ſouth.

A very aſtoniſhing property of light upon the vegetable kingdom is, that when vegetables are expoſed to open day-light, or to the ſun's rays, they emit vital air.†

It has been proved, that the ſun does not act in the production of this phenomenon as a body which heats. The emiſſion of the air is determined by the light; pure air is therefore ſeparated by the action of light, and the operation is ſtronger as the light is more vivid. It would ſeem that light favours the work of digeſtion in the plant, and that the vital air which is one of the principles of almoſt all the nutritive juices, more eſpecially of water, is emitted when it finds no ſubſtance to combine with it in the vegetable. Hence plants, whoſe vegetation is the moſt vigorous, afford the greateſt quantity of air.

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* Chaptal's Elements of Chemiſtry.

† Lecture x.

By this continual emiſſion of vital air, the Author of nature inceſſantly repairs the loſs thereof occaſioned by reſpiration, combuſtion, and the alteration of bodies, including every kind of fermentation and putrifaction: in this manner the equilibrium is always maintained between the conſtituent parts of the atmoſphere.

Scheele and Berthollet have ſhewn, that the abſence or preſence of light has an aſtoniſhing effect upon the reſult of chemical experiments: Light diſengages vital air from ſeveral fluids, ſuch as the nitrous acid, dephlogiſticated marine acid, &c.; it reduces the calces of gold, ſilver, &c.; it changes, according to Mr. Berthollet, the nature of oxigenated muriates. M. Chaptal has ſhewn, that it determines the phenomena of vegetation, exhibited by ſaline ſolutions. Theſe circumſtances ſhew the importance of light, and how much it's agency in nature ſhould be attended to by every philoſopher: *heat* often accompanies light, but ſome of the phenomena, we have mentioned, cannot be attributed to mere heat; heat may indeed modify them where it exiſts, but is not the producing cauſe.

There are many inſtances where the action of the ſolar light contributes to the deſtruction of colour, and inſtead of extricating vital air, fixes it, and produces a kind of combuſtion. In like manner phoſphorus, while in the dark, is not affected by the oxigenated muriatic acid, even aſſiſted by heat; but when the action of light concurs, it is converted into phoſphoric acid.*

A variety of facts ſhew, that vital air is capa-

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* Berthollet's Art of Dyeing.

ble of whitening or rendering paler the colouring matter with which it unites, perhaps by having produced on them the effects of a ſlight combuſtion.* Vital air has conſiderable influence on the colouring particles of vegetables; theſe are formed chiefly in the leaves, flowers, and inner bark of trees, and by degrees they undergo a ſlight combuſtion: hence moſt trees contain fawn-coloured particles.

The manner in which the ſun acts upon colours may be ſeen by examining the appearances preſented by a ſolution of the green part of vegetables in alcohol.

If ſuch a ſolution, which is of a fine green colour, be expoſed to the light of the ſun, it very ſoon acquires an olive hue, and loſes it's colour in a few minutes. If the light be weak, the effect is ſlower; and in perfect darkneſs the colour remains without alteration, or requires a great length of time.

M. Berthollet inverted over mercury a bottle half full of this green ſolution; when the colour was diſcharged, the mercury was found to have riſen in the bottle, and conſequently vital air had been abſorbed, the air having united with the colouring matter; on evaporating this liquor, it's colour was immediately rendered darker, and became brown: the reſiduum was black, and in the ſtate of charcoal.

The light ſeemed therefore to have produced it's effect by favouring the abſorption of vital air, and the combuſtion of the colouring matter; the marks of combuſtion are not evident at firſt, but by the aſſiſtance of heat the liquor becomes brown, and leaves a black reſiduum. If the veſſel containing the liquor holds no vital air, the light has no effect on the colouring matter.

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* See what was ſaid on incipient ignition, under the article of phoſphori.

The effects of light on the colour of wood have been long obſerved; it preſerves it's natural appearance while kept in the dark, but when expoſed to the light it becomes yellow, brown, or of other ſhades. M. Senebier found, that the changes were proportioned to the brightneſs of the light, that ſeveral folds of ribbon were required to defend the wood completely, that a ſingle leaf of black paper was ſufficient; but that when paper of any other colour was ſubſtituted, the change was not prevented; a ſingle covering of white paper was inſufficient, but two intercepted the action of the light. Theſe obſervations are important, as they prove that light can paſs through coverings that appear to be opake, and exerts it's energy at ſome diſtance within.

M. Berthollet put tincture of turnſole in contact with vital air over mercury; one parcel he placed in the dark, the other was expoſed to the light of the ſun; the former continued unchanged for a conſiderable length of time, and the vital air was not diminiſhed; the other loſt much of it's colour, became red, and the air was in a great meaſure abſorbed, and a ſmall quantity of fixed air was produced, which no doubt had occaſioned the change of colour from blue to red.

This obſervation may lead us to form an idea of ſome of the changes produced by a particular diſpoſition of the component parts of vegetable ſubſtances, when by the combination of vital air they undergo the effects of a ſlight combuſtion, which may generate an acid; as in the leaves in autumn, which grow red before they become yellow, and in the ſtreaks obſervable in flowers, whoſe vegetation is growing languid.

The ſucceſs of the preſent age in arts, experiments, and new ſyſtems, is very apt to elate the minds of men, and make them overlook the ancients.

cients. But notwithſtanding the encouragement and purſe of princes, and the united endeavours of great ſocieties in theſe later ages, have extended experimental and mechanical knowledge; yet it muſt be owned, the ancients were not ignorant of many things, which are now more generally, though not firſt known. Their notions of fire and light, the reſult of obſervation, were for the moſt part juſt. They conſidered the principles of motion and vegetation as delibations from the inviſible fire of the univerſe, which, though preſent to all things, is not neverthelefs one way received by all; but variouſly imbibed, attracted, and ſecreted by the fine capillaries and exquiſite ſtrainers in the bodies of plants and animals, and is thereby mixed and detained in their juices. They ſuppoſed the elaborate ſpirit, whereon the character, diſtinguiſhing virtue, and properties of the plant depend, to be of a luminous and volatile nature.

It was from an etherial and luminous fluid that they derived the many and various qualities, virtues, odours, flavours, and colours, which diſtinguiſh natural productions; conceiving that the original particles productive of theſe properties were diverſely ſeparated, and attracted by the various ſubjects of the animal, vegetable, and mineral kingdoms, which thereby become claſſed into kinds; and indeed with thoſe diſtinct properties which continued till their ſeveral forms, or ſpecific proportions of fire, returned into the common maſs.

They conſidered all the appearances of fire, even in earthly things, as ſomething of a heavenly, exalting, and glorious nature; as that which diſperſes *death*, *darkneſs*, and *groſſneſs*, and raiſes up the power and glory of every *life*; that it was ſeldom ſeen in this world but as a *deſtroyer*, a *conſumer*, and *refiner* of *groſſneſs*; as a *kindler* of life and light out of death and darkneſs; that ſo much as any thing had of light, ſo much it had of heaven; and that this was rendered evident in the power of the ſun, and manifeſted in the *ſoftneſs* of ſounds, the *beauty* of colours, the *fragrance* of ſmells, and the *richneſs* of taſte.

Before I finiſh this Lecture, I muſt make a further obſervation on colour, on account of the miſchievous inferences deduced from the Newtonian theory, by Voltaire and ſome other infidel writers. Theſe men ſuppoſe that light and colour, as apprehended by the imagination, are only ideas in the mind, and not qualities that have any exiſtence in matter. Strange as this may ſeem, it has been univerſally received, and conſidered by ſome as one of the nobleſt diſcoveries of modern philoſophy.

By colours all men, who have not been tutored in this ſchool, underſtand not a ſenſation of the mind, which can have no exiſtence when it is not perceived, but a quality and modification of bodies, which continues the ſame whether it be ſeen or not. The ſcarlet roſe, which is before me, is ſtill a ſcarlet roſe when I ſhut my eyes, and was ſo at midnight when no eye ſaw it; the colour remains when the appearance ceaſes; it remains the ſame when the appearance changes; for when I view this ſcarlet roſe, through a pair of green ſpectacles, the appearance is changed; but I do not conceive the colour in the roſe to be changed. To a perſon in a jaundice it has ſtill another appearance, but he is eaſily convinced the change is in his eye, not in the colour of the object. We can by a variety of optical experiments change the appearance of figure and magnitude in a body, as well as that of colour; we can make one body appear to be ten. But no man believes the multiplying glaſs really produces ten guineas out of one; in like manner, no one believes the coloured glaſs changes the real colour of the object ſeen through it, when it alters the appearance of that colour.

Colour is not a ſenſation, but a ſecondary quality of bodies, whereby in fair day-light they exhibit a certain and well underſtood appearance; and there is a real permanent quality in bodies, to which the common uſe of this word agrees. Had modern philoſophers given, as they ought to have done, the name of colour to the *cauſe* inſtead of to the effect, they would not have ſet philoſophy apparently in contradiction with common ſenſe; for they muſt then have affirmed with the vulgar, that colour is a property of bodies, and that there is nothing like it in the mind. Their language as well as their ſentiments would have been perfectly agreeable to the common apprehenſions of mankind, and true philoſophy would have joined hands with common ſenſe.*

Inſtead of ſeeking objections againſt revelation from every appearance in nature, the true philoſopher finds abundant ground therein to confirm and eſtabliſh his faith; he learns from the adaptation of objects to the ſenſes, the abſurdity of thoſe infidels, and their want of knowledge in the human underſtanding, who require for conviction a ſtronger evidence in the objects of faith, than is to be offered for thoſe of the other faculties.

In examining the objects of various parts of intellect, do not we find men at a loſs to prove in what manner they exiſt? Do they ſuſpend their aſſent to the reality of a roſe, till they can explain why the leaves are of a different colour, odour, and ſhape, from thoſe of the lily? or why they are of any particular ſmell, ſhape, or colour? Is it an objection to the evidence of the eye-ſight, that the ſounds of a violin are imperceptible by that organ?

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* Reid's Inquiry into the Human Mind.

or becauſe neither form nor ſound are the objects of reaſon, that neither of them exiſts? Would not a geometrician treat with contempt the perſon who ſhould deny the reality of the properties of a ſquare, becauſe they are irreconcileable with thoſe of a circle? All that is required in theſe inſtances, is a conſentaneous diſpoſition in the objects and the faculties to impart and receive thoſe ideas, and the mind reſts convinced of their realities.

The utility and pleaſure which are derived from the ſenſes are the great proofs which ſatisfy men of the reality of the *objects* of them. He whoſe eye-ſight prevents him from running over a precipice, whoſe ears are delighted with the powers of harmony, can entertain no doubt of the exiſtence of thoſe objects; and whoever ſhould attempt to prove that the firſt was not ſeen, and the latter not heard, would inevitably render himſelf an object of ridicule. And is not a man equally ridiculous, who denies that the objects of faith are real, though he is every day acquiring happineſs, and obtaining ſecurity, as the reſult of them? The adaptation of the doctrines of faith to the nature of man, and the ſuperior utility ariſing from it, are the ſtrongeſt proofs of it's divine original; their principles correſpond to the faculties and wants of human nature, and it's precepts to their welfare.

To deny theſe proofs would be to reject all moral evidence, and even the exiſtence of a *Deity*. When we perceive all parts of matter fitted to the uſes of creation; when we ſee that rain and ſun are neceſſary to vegetation, and that the order and courſe thereof is ſuch, that they never fail the purpoſes of their intentions; is it poſſible to deny the *Providence* of a *ſupreme* intelligence? In like manner, when it is diſcovered that all parts of our religion coincide as perfectly with the nature of man and his welfare, is it not equally abſurd to reject it as proceeding from the ſame ſource?

Whoever conſults the ſenſations of his own mind, will feel the evidence of the hereditary evil of man as evincing, as the dry leaf is expreſſive of it's having been in a more perfect ſtate. What are the preſentiments and preſages of the ſoul, but the remains of a more perfect intelligence? And what is that abatement of pleaſure which enjoyment taſtes, compared with the felicity imagination preconceives, but an indication of the defect in human faculties? Like the evaneſcent colours of a declining tulip, they pronounce their former excellence.

The ſenſe of degradation, and of it's being irremediable by the powers of man, creates thoſe deſires in the human breaſt which are conſtantly yearning after a better ſtate, and the belief of the neceſſity of a more perfect being to reſtore it. Here the idea of infinite mercy, inſeparable from the Divine Being, leads the ſoul to ſee that it's redemption can only be accompliſhed by the Supreme Being. Thus you may perceive, that the truths of chriſtianity are obvious and plain; they ſpeak the language of nature; and all nature is expreſſive of the ſenſe and ſound thereof; and points out the neceſſity of a REDEEMER, whoſe exiſtence and influence is as extenſive as nature itſelf.

To ſhew that nothing under him, "in whom we live, and move, and have our being," could redeem us, our REDEEMER, when he had ſhrouded his BEAUTY with the veil of mortality, gave hourly and ocular proofs of his GODHEAD by the extent of his power in and over all things. "In HIS WORD was LIFE, in HIS BREATH was healing, and ſickneſs grew ſound at HIS ſight; the lame ſprang up at HIS bidding, by HIM the deaf ear was opened, and the dumb tongue looſed to utterance; HE poured the beams of his light upon the new opening eyes of the blind-born gazer; death fled before HIM, and amidſt the tombs HIS WORD was *life* and *reſurrection*; the *tempeſt* heard HIS voice and was ſtill; the *earth* trembled with reverence; and the *ſea* ſpread itſelf as a carpet beneath the foot of her CREATOR.

————————" Yet
" Even all his mighty works to me import,
" But as they greatly ſerve to authorize
" The mightier words he uttered—as the eye
" Bears witneſs to the light, or the charm'd ear
" To tuneful undulation; for the heart
" Strikes uniſon to his great law of LOVE,
" And proves his miſſion all DIVINE."

LECTURE XXII.

ON TELESCOPES.

IN our laſt Lectures, I endeavoured to render plain and eaſy to your comprehenſion, ſome of the great diſcoveries of Sir ISAAC NEWTON, who ſurpaſſed himſelf in his *Theory of Light and Colours*, as much as he had exceeded others in his *Principia*. Both theſe works give teſtimony to the depth and clearneſs of his intellect, his ſkill in conducting experiments, and the comprehenſive force of his mind. But far as he has penetrated into the receſſes of light, the ſame Lectures muſt have convinced you, that many appearances are yet unexplained, many difficulties are yet unexplored; and that the inſtances are numerous which prove, that the inward conſtitution, the real cauſes, and connections of the moſt obvious phenomena, are beyond your apprehenſion.

Vanity in any man is weakneſs; but a vain philoſopher is the moſt abſurd among men, for every new diſcovery demonſtrates his imbecility; every new effect that is brought to light, ſerves only to convince him of innumerable others which remain concealed, and of which he had no previous knowledge: the works of GOD are too vaſt, and of too large an extent for our capacities. There is ſuch an expanſe of power, wiſdom, and goodneſs, in the formation of the world, as is too mighty for our graſp, too much for us to comprehend. Power, wiſdom, and goodneſs, are manifeſt to us in all thoſe works of GOD which are within our view: but there are likewiſe infinite ſtores of each poured ſorth throughout the immenſity of the creation, no part of which can be underſtood without taking in it's reference and reſpect to the whole, and this is beyond the reach of human faculties. *To whom hath the root of wiſdom been revealed? or who hath known her wiſe counſels? There is one wiſe and greatly to be feared, the* LORD *ſitting upon his throne.* HE *created her, and ſaw her, and numbered her, and poured her out upon all his works.*

Theſe reflections naturally occur to the mind when it contemplates the diſcovery of the teleſcope, and the advantage ariſing from it; for who, reaſoning *a priori*, could have imagined that the refraction of light in glaſs, the ſame power by which a ſtrait rod appears crooked in water, whereby viſion is variouſly diſtorted, and whereby we are liable to innumerable deceptions, ſhould ever be ſo circumſtanced as to extend the boundaries of ſight, and enable us to diſtinguiſh objects too remote for natural viſion? Yet ſuch are the powers ſcience has beſtowed, that by glaſſes, properly adapted to each other, we as it were contract ſpace, and bring within our ken the grander objects of the univerſe; and are enabled to extend our inquiries beyond the boundaries of the ſolar ſyſtem.

If Pliny, in regard to *Hipparchus*, could extravagantly ſay; "*Auſus rem Deo improbam annumerare poſteris ſtellas,*" what would that pompous hiſtorian of nature have ſaid, had it been foretold him, that in the latter days a man would ariſe, who ſhould enable poſterity to enumerate more new ſtars, than *Hipparchus* had counted of the old; who ſhould aſſign four moons to Jupiter, and in our moon point out higher mountains than any here below; who ſhould in the ſun, the fountain of light, diſcover dark ſpots as broad as two quarters of the earth, and by theſe ſpots aſcertain his motion round his axis; who, by the varying phaſes of the planets, ſhould compoſe the ſhorteſt and plaineſt demonſtration of the ſolar ſyſtem? Yet theſe were but part of the annunciations to the world of a ſingle perſon, of *Galileo*, of unperiſhing memory! To him, his cotemporary and rival in fame, *Lord Bacon*, aſcribed the invention of *perſpicilla*, (for ſo at firſt were called the teleſcopes,) and in a figurative ſtrain thus expreſſed himſelf concerning them: " With theſe (perſpicilla), which *Galileo*, by a memorable effort of genius, hath diſcovered, we are enabled, as with ſome ſmall ſailing veſſels, to open and keep up a nearer commerce with the ſtars."

Nor did the celeſtial commerce ceaſe with the acquiſitions of Galileo, but has been extending ever ſince the time that that great man firſt turned his glaſſes to the heavens.* In our own day the energy and philoſophic enthuſiaſm of *Herſchell* has enlarged the boundaries of aſtronomical knowledge, added a new planet to our ſyſtem; the heavens have, as it were, increaſed under his eye; and 44000 ſtars, ſeen in the ſpace of a few degrees, ſeem to indicate that ſeventy-five millions may be diſcovered in the expanſe expoſed to human inveſtigation.

What is neceſſary for the conduct of our animal life, the bountiful AUTHOR of nature has made manifeſt to all men. But there are many other choice ſecrets of nature, the diſcovery of which enlarges the power and exalts the ſtate of man; theſe are left to be diſcovered by the uſe of our rational powers; they are hid, not that they may be always concealed from human knowledge, but that we may be excited to ſearch for them: this is the proper buſineſs of a philoſopher; and it is the glory of a man, and a reward for his labour, to diſcover that which has been thus concealed.

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* Sir John Pringle's Diſcourſes, p. 228.

Thus in the ſubject before us, our eyes are incapable of diſcerning objects, either very ſmall or very diſtant; but the CREATOR has given properties and qualities to matter by which it may procure us theſe advantages: HE elevated the underſtanding from one degree of knowledge to another, till it was able to diſcover theſe aſſiſtances for our ſight. It is to the ſame *power*, therefore, who created the objects of our admiration, that we are ultimately to refer the means of their diſcovery; and whatever we find out by their means, becomes a freſh ſource of praiſe to HIM from whom we receive every bleſſing.

The very great importance of the teleſcope has made the firſt diſcovery of it an intereſting object of inquiry; but no reſearch has been able to aſcertain either the exact period when it was firſt found out, or who was the inventor. It has been by ſome, and with no ſmall degree of probability, attributed to the famous friar, Roger Bacon, before the year 1300, and it is worth your while to be acquainted with ſome of his expreſſions. *Lenſes and ſpecula may be ſo figured, that one object may be multiplied into many; that thoſe which are ſituated at a great diſtance may be made to appear very near; that thoſe which are ſmall may be made to appear very large, and thoſe which are obſcure very plain; and we can make ſtars to appear wherever we will.* Theſe and other expreſſions and tracts of this author ſeem to indicate, that he was well acquainted with the nature, conſtruction, and uſe of teleſcopes, and all the glaſſes which compoſe them; but ſome modern critics in the ſcience not only deny him the invention, but even the knowledge of any ſuch conſtruction, as we at preſent call teleſcopes, though he mentions the refractions of the ſun's rays through a glaſs ſphere; but as he does not ſay, *totidem verbis*, that he ever viewed an object through ſuch a ſphere, Dr. Smith ſuppoſes that he had no experience of it's magnifying power. In the ſame manner, had *Seneca* deſcribed his glaſs ball, filled with water, only as a burning-glaſs, it might have tempted us to argue that he knew nothing of it's uſe in *magnifying letters*; but he has precluded conjecture by declaring the contrary. He might know more than is ſpoken of; the mathematicians and workers in glaſs of thoſe days might know more than he did. From the foregoing and other expreſſions of our countryman, *Friar Bacon*, there is little doubt but that he was acquainted both with ſpectacles and teleſcopes.

"Friar Bacon," ſays the Rev. Mr. William Jones, "may be conſidered as the firſt of Engliſh philoſophers; his profound ſkill in mechanics, optics, aſtronomy, and chemiſtry, would make an honourable figure in the preſent age; but he is entitled to further praiſe, as he made all his ſtudies ſubſervient to theology, and directed all his writings, as much as could be, to the glory of God. He had the higheſt regard for the ſacred ſcriptures, and was perſuaded they contain the principles of all true ſcience. He had a liberal way of conſidering things, not adhering ſervilely to his ſubject, but uſing all the ſciences of which he was maſter to illuſtrate each other. It is very unjuſt to ſpeak of philoſophy, as if it was unknown till the laſt century, when in reality a ſcholar furniſhed with no materials, but ſuch as might be extracted from Friar Bacon's works, would yet be a very conſiderable perſon, and entitled to no ſmall degree of fame among the literati of the preſent age. He would excel as a mathematician, experimentaliſt, phyſician, chemiſt, artiſt, aſtronomer, philoſopher, and divine."

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* Jones's Phyſiological Diſquiſitions, Introduction. Duten's Inquiry into the Origin of Modern Diſcoveries. Biographia Britannica.

Men of learning have been divided in their opinions concerning the optical konwledge of the ancients; ſome are ſo ſwallowed up by an admiration of the diſcoveries that have been made in the laſt and preſent century, that they have been tempted to paſs ſentence upon the ancients, before they knew what the ancients have ſaid for themſelves. It is ſaid, indeed, that if dioptric glaſſes were anciently in uſe, it is ſtrange we find them ſo ſeldom mentioned in their writings. This may be hard to account for, but it is unſafe to draw a poſitive concluſion from negative evidence. The accounts we have of many ancient works of art are ſo much broken by the injuries of time, the ambiguities of language, the ſucceeding intereſts of different ſects of philoſophers, the barbariſm of ſucceeding ages, that it is now very difficult to eſtabliſh the ſuppoſition by ſatisfactory proofs.

If we argue by *inference*, the caſe will be a little altered. The cabinets of the curious contain ſome very ancient gems, of admirable workmanſhip, the figures on which are ſo ſmall, that they appear beautiful through a magnifying glaſs, but altogether confuſed and indiſtinct to the naked eye: and if they cannot be viewed, how could they be wrought without the aſſiſtance of glaſſes? How could it be known that the moon has a form like that of the earth; that it has plains, hills, and vallies in it? When it is ſeen through a teleſcope, the diſpoſition of light and ſhade render this evident, agreeable to the common rules of perſpective; but no ſuch thing appears to the naked eye. How could it be known that the *via lactea* ariſes from the combined rays of an infinite number of ſmall ſtars? But above all, how came it to be aſſerted, *that the ſphere of the fixed ſtars is ſo immenſe, that the circle of the earth's annual orb bears no greater proportion to it than the center of any ſphere bears to it's whole ſurface?* This diſcovery does ſo far exceed the comprehenſion of the human mind, that it was not aſſerted after the revival of the *Pythagorean* ſcheme, till Dr. Bradley, by a courſe of the moſt accurate obſervations that ever were made with a *teleſcopic* apparatus, reduced the *annual parallax* of the fixed ſtars to an inſenſible quantity.

If leaving the ancients we return to the moderns, we find the time of the invention, and the name of the inventor, are ſtill involved in obſcurity. By ſome it is aſcribed to James Mœtius, a Dutchman; by others to John Lepperſheim, of Middleburg: but Borellus, in a circumſtantial and apparently well authenticated account, attributes the invention to Zacharias Janſen, of Middleburg, about the year 1590. Janſen was a diligent inquirer into nature, and being engaged in theſe purſuits, and trying what advantages could be derived from combining lenſes, fortunately diſcovered the teleſcope.

The wonderful effects of this inſtrument ſoon reached Galileo, who, ſetting himſelf to work, contrived an inſtrument to effect the ſame purpoſe. As this ſubject is ſo curious and intereſting, I think you will be pleaſed with his own account of it, as publiſhed in a book intitled, *Nuncius Siderius*, in March, 1610. "Near ten months ago," ſays he, "it was reported that a certain Dutchman had made a perſpective, through which many diſtant objects appeared as diſtinct as if they were near; ſeveral effects of this wonderful inſtrument were reported, which ſome believed, and others denied: but having had it confirmed to me a few days after by a letter from the noble John Badoveric, Badoverie, at Paris, I applied myſelf to conſider the rationale thereof, and by what means I might contrive a ſimilar inſtrument, which I afterwards attained to by the doctrine of refraction; and firſt I prepared a leaden tube, to whoſe extremity I fitted two ſpectacle-glaſſes, both of them plain on one ſide; on the other one of them was ſpherically convex, and the other concave. I ſaw objects appear pretty large, and pretty near; they appeared three times nearer, and nine times larger in ſurface than to the naked eye: and ſoon after I made another, which repreſented objects above 60 times larger; and at laſt, having ſpared no labour or expence, I made an inſtrument ſo excellent as to ſhew things almoſt a thouſand times larger, and above thirty times nearer than to the naked eye."

If the true inventor is he who makes diſcovery by reaſoning *a priori*, and deſcending from eſtabliſhed principles to their conſequences, Galileo may be conſidered as the real inventor of the teleſcope; but the uſe he made of it does him more honour than the invention: the inſtrument was at firſt, in Holland, a mere article of curioſity, not an inſtrument of ſcience; himſelf being amply rewarded by prevailing over the difficulty of the ſubject, and with new diſcoveries which enlarged the territories of reaſon.

OF REFRACTING TELESCOPES.

By a *teleſcope* is uſually ſignified an inſtrument that renders the view of diſtant objects more perfect; or, in more general terms, which repreſents diſtant objects under a larger angle than that under which they appear to the naked eye.

When the diſtance of the object is very conſiderable, the effects may all be referred to the ſame diſtance, and a teleſcope may be ſaid to enlarge an object juſt as many times as the angle under which it repreſents it is greater than that under which it appears to the naked eye. Thus the moon appears to the naked eye under an angle of about half a degree; conſequently a teleſcope magnifies 100 times, if it repreſents the moon under an angle of 50 degrees; if it magnified 200 times, it would exhibit the moon under an angle of 100 degrees; and the moon would appear to occupy more than half the viſible heavens, of which the whole extent is only 180 degrees.

It is a common expreſſion, that teleſcopes bring objects nearer; but this expreſſion is equivocal, admitting of two different ſignifications. The one is, that, looking through a teleſcope, we eſtimate an object to be as much nearer to us as it is magnified by the teleſcope. But I have already ſhewn you, that we can form no certain eſtimate of the diſtance of an object but by the judgment, and that our judgment deceives us when the objects are beyond a certain diſtance; and in the preſent inſtance, loſing all thoſe ſubjects of compariſon on which it is founded, will deceive us more. The other meaning applied to the expreſſion is, that the teleſcope repreſents the objects as large as they would appear if we were ſo much nearer to them: this latter meaning is more conformable to the truth than the preceding, for you know that the nearer we approach to an object the larger is the viſual angle. When you look, however, at a well known object, as a man, at a great diſtance, and he is ſeen under a larger angle, we are led to think him ſo much nearer, when he would really appear under a greater angle; but with reſpect to objects leſs known, as the ſun and moon, there can be no eſtimation of diſtance.

One principal end of teleſcopes is to enlarge or multiply the angle under which objects appear to the naked eye, and they are eſtimated according to this effect, and are ſaid to magnify five, ten, or any other number of times, according to the nature and conſtruction of the teleſcope.

This diagram, *fig.* 13, *pl.* 6, repreſents a ſmall Galilean teleſcope: the convex lens P, P, is directed toward the object, the concave glaſs Q, Q, is applied to the eye; on this account the one neareſt to the eye is called the *eye-glaſs*, that towards the object-glaſs is called the *object-glaſs*. Theſe glaſſes are ſituated upon the ſame axis A B, which paſſes through the center of the glaſſes, and to which they are perpendicular. The focal diſtance, or focus of the convex-glaſs, ſhould be longer than that of the concave, and the lenſes ſhould be ſo diſpoſed, that if A F be the focal diſtance of the convex lens P A P, the focal point of the concave glaſs ſhould fall upon the ſame point F. Thus the interval A B, between the two glaſſes, is the difference between their foci, A F being the focal diſtance of the object-glaſs, and B F that of the eye-glaſs. When the glaſſes are ſo placed, a common eye will ſee diſtant objects diſtinctly, and will magnify in the ſame proportion that the line A F exceeds the line B F. Thus, ſuppoſing the focus of the object-glaſs to be ſix inches, and of the eye-glaſs to be one inch, the interval between them will be five inches; the length of the teleſcope and the objects will be enlarged ſix times, that is, it will appear under an angle ſix times greater than what they do to the naked eye.

After having explained to you the manner in which the glaſſes are to be diſpoſed, in order to produce the deſired effect, it remains for me to ſhew you why they repreſent the objects diſtinctly, and why they are magnified as many times as the line A F exceeds that of B F. With reſpect to the firſt, I muſt juſt remind you of what has been before obſerved, that we ſee objects beſt when the rays that proceed from them and fall upon the eye are nearly *parallel* to each other.

This obſervation being attended to, you muſt now conſider another diagram, *fig*. 14, *pl*. 6. Let V be a point in the object towards which the teleſcope is directed, and as it is ſuppoſed to be very diſtant, the rays proceeding therefrom may be conſidered as parallel to each other; thoſe therefore that fall upon the object-glaſs Q A Q, will be united at it's focus F, and being convergent there, will not be adapted to produce diſtinct viſion for a common eye. Now it being the property of a concave glaſs to render rays more diverging, or to diminiſh their convergence, it will refract the rays Q R, Q R, ſo as to render them parallel to each other; ſo that inſtead of uniting at E, they will proceed in the direction R S, R S, parallel to the axis A R F, and thus the teleſcope will be fitted for diſtinct viſion.

I have now to explain the principal effect of teleſcopes, that is, their magnifying power; a ſubject which I hope to render ſo clear, that no doubts ſhall remain on your mind.

1. Let E e, *fig*. 3, *pl*. 7, be the object placed on the axis of he teleſcope, which paſſes through the center of the two lenſes. E e is to be conſidered as at an infinite diſtance.

2. If the eye placed at A look at this object, it will ſee it under the angle E e, called the viſual angle. What we have therefore to prove is, that in looking through the teleſcope it will appear under an angle as much larger than this, as the focal diſtance of the object-glaſs exceeds that of the eye-glaſs.

3. As the effect of all the glaſſes conſiſts in repreſenting the object in another place, and of a certain ſize, all we have to do is to examine the

different images, the laſt of which forms the object immediately viewed by means of the teleſcope.

4. Now the object E e being at an infinite diſtance from the convex lens P A P, it's image will be repreſented behind the glaſs at F f, and A F will be the focal diſtance of this glaſs; the ſize of this image F f, is determined by a ſtrait line from the extremity e of the object through A the center of the lens; conſequently this image is inverted, and as much ſmaller than the object, as the diſtance A F is ſmaller than the diſtance A E.

5. Now this image f F is to be conſidered as the object with reſpect to the eye-glaſs Q B Q, ſince the rays that fall upon this glaſs are thoſe which would form the image F f, but that they are intercepted in their paſſage by the concave glaſs Q B Q; ſo that though the image is only imaginary, the effect is the ſame as if it were real.

6. The image F f, that we may now conſider as an object, being at the focal diſtance of the lens Q B Q, will be tranſported to an infinite diſtance by the refraction of the glaſs. This new image is marked in the figure by G g, of which the diſtance A G ſhould be conſidered as infinite; and the rays being a ſecond time refracted by the glaſs Q B Q, will continue the ſame direction as if they came from the image G g.

7. This ſecond image G g, being the object that is ſeen by him who looks through the teleſcope, we muſt conſider it's ſize. Now as it ariſes from the firſt image F f, and the refraction of the glaſs Q B Q, draw according to the general rule from B the middle of the concave glaſs a line paſſing through f the extremity of the firſt image, and it will mark at g the extremity of the ſecond image.

8. Now as the ſpectator applies his eye at B, and as the rays that fall upon his eye are received as if they came from the image G g, it will appear under the angle G B g evidently larger than the angle E A e, under which the object E e appears.

9. To compare theſe angles, I muſt inform you that the angle E A e is equal to the angle F A f, and the angle G B g is equal to the angle F B f. I have now therefore only to prove that the angle F B f exceeds the angle F A f, as much as the line A F exceeds the line B f.

10. To prove this, we muſt have recourſe to certain propoſitions deduced from geometry, concerning the nature of ſectors. You probably remember that a ſector is an arch of a circle included between two radii; thus C M N, *fig.* 4, *pl.* 6, is a ſector of a circle; C M, C N, the two radii; M N the arch or portion of the circumference. There are therefore three things to be conſidered in a ſector: 1. The radius of the circle, as C M, C N. 2. The quantity of the arch M N. 3. The angle M C N.

11. Let us now conſider the two ſectors M C N, and m c n, *fig.* 4, *pl.* 6, of which the radii C M and c m are reſpectively equal. Geometry proves, that in this caſe the angles C and c are in the ſame ratio as the arcs M N and m n; or in other words, that the angle C is ſo many times larger than the angle c, as the arc M N is larger than the arc m n; or in more general terms, when the radii are equal, the angles are proportional to their reſpective arches.

12. In the two ſectors M C N and m c n, *fig.* 5, *pl.* 6, the angles are equal, but the radii are unequal. The elements of geometry prove, in this caſe, that the arc M N is ſo many times greater than the arc m n, as the radius C M is greater than c m; or that the arcs are proportional to the reſpective radii

when the angles are equal. The reaſon is evident, for each arc contains the ſame number of degrees; but the degrees of a large circle are as much larger than thoſe of a ſmall one, as the longer radius exceeds the ſmaller one.

13. In the two ſectors M C N and m c n, *fig.* 6, *pl.* 6, the arcs are equal, but the radii are unequal. Here the angle C, which anſwers to the longeſt radius, is the ſmalleſt, and that in the ſame ratio as the radii; or the angle c is ſo many times larger than the angle C, as the radius C M is larger than the radius c m; or in more general terms, the angles are reciprocally proportional to the radii when the arcs are equal.

14. The laſt article comes more immediately to our purpoſe, with the addition of this obſervation, that when the angles are very ſmall (as is the caſe in ſmall Galilean teleſcopes), the arcs M N and m n do not differ ſenſibly from their cords, or the ſtrait lines M N and m n.

15. We may now return to the former diagram. The triangles F A f, F B f, may be conſidered as ſectors, and the arc F f as common to both; conſequently the angle F B f exceeds the angle F A f, as much as the diſtance A F exceeds that of B F; or the object E e will appear in the teleſcope under an angle as much larger than that under which it appears to the naked eye, as the focal diſtance of the object-glaſs exceeds that of the eye, which was what I had to prove to you.

You will eaſily comprehend from what has been ſaid, that very great advantages are not to be expected from a teleſcope conſtructed on this plan; for in order to obtain any conſiderable magnifying power, it muſt be made very long, a circumſtance that renders it inconvenient in uſe. Beſides this there are other diſadvantages, among which the ſmallneſs of the apparent field is the principal.

This naturally leads me to conſider the nature of the *apparent field*, which is an article of great importance in all teleſcopes. When you direct a teleſcope towards the heavens or any other diſtant object, the ſpace diſcovered appears of a circular form, and no objects are ſeen but what are contained within this circle; ſo that if you are deſirous of viewing other objects, you muſt change the poſition of the teleſcope; this circular ſpace is called the *apparent field*, or ſimply the *field of view*. Hence you will readily conceive, that it muſt be a great advantage to have a teleſcope with a large field, and that a ſmall field muſt be conſidered as a defect.

As a large field is a great perfection in a teleſcope, it is often neceſſary to meaſure the field; this is generally attained by meaſuring the number of degrees contained in the ſpace taken in by the teleſcope, when directed to the heavens, or to ſome very diſtant object. Thus as the apparent diameter of the full moon is about half a degree, if a teleſcope only takes in the moon, we ſay it's field is half a degree; but if you only ſee one half of the moon, the field would only be a quarter of a degree.

But in order to judge rightly of the field of a teleſcope, you muſt take in the magnifying power; for it is an univerſal maxim, that the more a teleſcope magnifies, the ſmaller is the field: nature here preſcribes the boundaries. Let P A P, *fig*. 3, *pl*. 7, be the object-glaſs, Q B Q the eye-glaſs of a teleſcope, E F the axis thereof, E e an object at a great diſtance, ſeen under the angle E A e, which repreſents half the diameter of the apparent field; which extend as much on one ſide the axis as on the other. The point E is the center of the field; the ray E A is not refracted as it paſſes through the middle of the glaſſes, perpendicular to their axis:

in order therefore that this ray ſhould enter the eye, the eye muſt be placed ſomewhere on the axis B F, behind the eye-glaſs, and ſo that the pupil may be on the line B F; this is a general rule with reſpect to all teleſcopes. Let us now conſider the viſible extremity e of the object; and of this it is plain that the extremity e of the object cannot be ſeen unleſs the ray e A proceeding therefrom enters the eye.

Let us then conſider the direction of the ray e A; now, according to the laws of refraction, this ray is not refracted, becauſe it paſſes through the middle of the object-glaſs A. This ray will therefore continue in the ſame direction to unite with other rays proceeding from the ſame point e, to form at f an image of the object repreſented by f F, the point f being the image of the point e of the object e E: but this ray meeting at m the concave glaſs, and not falling on the middle thereof, will be refracted; and inſtead of proceeding to f, will proceed in the direction m n, more diverging from the axis B F. You remember that the object-glaſs forms an inverted image of the object at F f, and that F f becomes the object with reſpect to the eye-glaſs, by which it is tranſported to G g. The diſtance B G is as great as that of the object, becauſe F f is in the focus of the eye-glaſs.

With reſpect to the ſize of the images, the firſt F f is determined by the ſtrait line e A f, drawn from e through the middle of the glaſs P A P; and that of the other G g, by a ſtrait line f B g, drawn from f through B the middle of the eye-glaſs. The ray A m directed towards the point f is refracted and proceeds towards m n, and this line continues backwards, paſſes by g, for the ray m n produces the ſame effect upon the eye as if it proceeded really from g. Now as m n diverges from B F, where the pupil of the eye is placed, it cannot enter the eye if it diverges further than the limits of the pupil of the eye; ſo that in this ſpecies of teleſcope the field depends on the ſize of the pupil of the eye, and the larger this is the larger is the field; ſo that if the diſtance B m does not exceed the ſame diameter of the pupil of the eye, and that this field may not be diminiſhed, the eye ſhould always be placed as near as poſſible to the eye-glaſs.

To determine then the ſize of the field in theſe teleſcopes, you have only to take the interval B m equal to the ſemidiameter of the pupil, and then draw a line m A e from m, and the middle of the object glaſs, and this line will mark upon the object that extremity e which will be viſible by the teleſcope, and the angle e A E will give the ſemidiameter of the field. From this it is very evident, that if the diſtance between the two glaſſes exceeds a few inches, the angle B A m will become very ſmall, becauſe the diſtance B m is only about the $\frac{1}{10}$ of an inch. Now, in order to magnify much with theſe teleſcopes, the diſtance between the glaſſes muſt be conſiderably increaſed, in which caſe the field would be infinitely ſmall; ſo that the extent of theſe teleſcopes is limited by the nature of their conſtruction, and the optician, in order to produce great effects conveniently, is obliged to have recourſe to other kinds.

A SUMMARY VIEW OF THE PROPERTIES OF THE GALILEAN TELESCOPE.

1. The focal diſtance of the object-glaſs muſt be greater than that of the eye-glaſs, or it will not magnify an object.

2. The magnifying power is equal to the quotient, ariſing by dividing the focal diſtance of the object-glaſs by that of the eye-glaſs.

3. The rays proceeding from the eye-glaſs to the eye, are nearly parallel; if this does not ſuit the eye, the tube containing the eye-glaſs muſt be put in, or drawn out a little, till the object appears diſtinct.

4. The viſible area of the object is greater, the nearer the eye is to the glaſs, and depends on the diameter of the eye's pupil, and of the object-glaſs; the field of view is therefore very ſmall.

5. If this teleſcope be long, the viſible area is ſo ſmall as to render it uſeleſs; this ariſes from the ſmallneſs of the object-glaſs; but if this be broader, the object will be coloured and confuſed.

OF THE ASTRONOMICAL TELESCOPE.

The next kind, which is denominated the *aſtronomical teleſcope*, conſiſts alſo only of two lenſes, and both of them are convex. Let P A P, *fig.* 15, *pl.* 6, repreſent the object-glaſs which is convex, and whoſe focus is at F; Q Q a deeper and ſmaller convex lens for the eye-glaſs, which is to be fixed upon the ſame axis, ſo that it's focus may coincide with the point F; holding the eye at o, ſo that the diſtance B O be nearly equal to the focal diſtance of the eye-glaſs. With a teleſcope conſtructed in this manner objects will be ſeen diſtinctly, and magnified in the ſame proportion as the focus of the object-glaſs exceeds that of the eye-glaſſes; but it repreſents all objects inverted, which does not leſſen it's value for aſtronomical purpoſes, but renders it inconvenient and improper for viewing terreſtrial objects.

I have to explain to you, 1ſt, How this arrangement of glaſſes ſhews diſtant objects diſtinctly. 2d, Why it magnifies in the ſame proportion as the focus of the object-glaſs exceeds that of the eye-glaſs, and exhibits the objects in an inverted poſition. And, 3d, Why the eye is not to be placed cloſe to the eye-glaſs, as in the former conſtruction.

1. The firſt article is proved in a ſimilar manner to the ſame article in the preceding conſtruction; the rays e P, e P, which are parallel to each other, before they fall upon the object-glaſs, are thereby refracted and united at it's focus; in order therefore for diſtinct viſion, the eye-glaſs muſt re-eſtabliſh the paralleliſm of the rays, which is effected by placing the eye-glaſs ſo that it's focus may be at F, and conſequently the rays will proceed from it's parallel to each other, and fall upon the eye in that direction.

2. For the explanation of the ſecond article, let us conſider the object e E, *fig.* 16, *pl.* 6, ſuppoſed to be placed at an infinite diſtance. The image of this object formed by the object-glaſs, at it's focus, will be F f; this image will be inverted, and become an object for the eye-glaſs, and being ſituated at it's focus the image will be at an infinite diſtance, ſuppoſe at G g, A G being conſidered an infinite diſtance as well as A E. Now to determine the ſize of this image, draw a ſtrait line B f g through B the middle of the lens, and the extremity f of the image. This ſecond image is the immediate object of viſion, and being at an infinite diſtance will be ſeen under the angle G B g; but the object itſelf is ſeen under the angle E A e. I ſcarcely need obſerve to you, that it is indifferent where the points A and B are taken, as the diſtance is conſidered as infinite. The triangles F A f, F B f, may, as in the preceding conſtruction, be conſidered as ſectors of a circle, the line F f being an arch common to both, for the angles are ſo ſmall that the chord may be taken for the arch; A E and B F are the reſpective radii, and the arches are equal; and of courſe, as I have proved

before, the angles F a f (or E A e) and F B f (or G B g) are in the ſame ratio as the radii B F and A F. Therefore the angle G B g, under which the object is ſeen by the teleſcope, is ſo much larger than the angle E A e, under which the object is ſeen by the naked eye, as A F is larger than B F.

3. With reſpect to the place of the eye, the proper ſituation thereof is determined by the field; for if you remove it either way from the focus of the eye-glaſs, the field is diminiſhed. It is a great advantage in teleſcopes of this conſtruction, that by removing the eye from the eye-glaſs, the field may be to a certain degree increaſed; and it is owing to this that the magnifying power of theſe may be ſo much increaſed, which will be evident by the following conſiderations:

1. Let E e, *fig.* 17, *pl.* 6, be the object at an infinite diſtance, e the extremity viſible by the teleſcope, whoſe glaſſes P A P, Q B Q, are ſituated on the axis E A B O; we have now to conſider the direction of the ray *e*, which proceeds from the extremity of the object through the middle of the object-glaſs; for the other rays proceeding from the ſame point *e*, only contribute to ſtrengthen the effect produced by this ray.

2. The ray e A paſſing through the middle of the glaſs P P is not bent, but paſſing on in the direction A f M, paſſing by the extremity f of the image, and falling upon the eye-glaſs at M. Here it is neceſſary to obſerve, that if the eye-glaſs is not large enough to reach M, this ray would not enter the eye, and the point e would be inviſible; that is, in other words, the extremity e muſt be placed nearer the axis, to make the ray A f M fall upon the eye-glaſs.

3. This ray A M will be refracted by the eye-glaſs; the mode of it's refraction will be eaſily inveſtigated: to this end let us conſider the ſecond

image G g. Now the line B prolonged, falls upon g, the extremity of the ſecond image, and the refracted ray takes the direction N O, which being prolonged falls upon g.

4. Since then the two lines O N and B f meet at g at an infinite diſtance, they may be conſidered as parallel to each other; therefore, to determine the poſition of the refracted ray N O, we have only to draw a line parallel to the line B f.

5. From hence it is evident, that the ray N O muſt meet with the axis of the teleſcope as at O; and ſince generally when the magnifying power is great, the point F is much nearer the glaſs Q Q than the glaſs P P, the interval B M will be a little larger than the image F f; and as the line N O is parallel to f B, the line B O will be almoſt equal to B F, the focal diſtance of the eye-glaſs.

6. The eye being placed at O will receive not only the rays which come from the middle of the object E, but alſo thoſe which proceed from the extremity e, and conſequently thoſe which come from all other parts of the object; the rays from B O and N O will fall at the ſame time on the eye, however ſmall the pupil may be; the field therefore in this conſtruction does not depend upon the ſize of the pupil, provided the eye be placed at O, but the moment the eye is removed from O, the apparent field is diminiſhed.

7. If the point M was not at the extremity of the eye-glaſs, it would tranſmit rays that were further removed from the axis, and the field would be larger. Therefore to determine the field of which the teleſcope is capable, draw from A the middle of the object-glaſs, to M the edge of the eye glaſs, the line A M; this continued to e, the object will mark the viſible extremity thereof, conſequently the angle E A e or B A M gives the ſemidiameter of the apparent field, which is conſequently,

ſequently augmented in proportion as the eye-glaſs is larger. In the firſt kind the field depended on the aperture of the pupil of the eye, in this it depends on the aperture of the eye-glaſs.

By the object-glaſs the object is carried from E e to F f; by the eye-glaſs it is as it were removed from F f to G g; the image G g, from being at ſuch a diſtance, is ſeen diſtinctly. This image is ſeen by the eye at O under the angle G O g or B O N, while the object is ſeen by the naked eye under the angle E A e; the teleſcope therefore magnifies in the ſame proportion as the angle B O N is greater than the angle E A e. Now as N O is parallel to B f, the angle B O N is equal to the angle F b f, and the angle E A e is equal to F A f; therefore the magnifying power may be determined by the proportion between the angles F b f and F A f. Now F b f is as much larger than F A f, as the line A F is larger than the line B f, or as much as the focus of the object-glaſs exceeds that of the eye-glaſs.

SUMMARY OF THE PROPERTIES OF THE ASTRONOMICAL TELESCOPE.

1. The magnifying power is in the proportion of the focal diſtance of the object to the eye-glaſs.

2. The rays emerging from the eye-glaſs to the eye ſhould be parallel for a good eye; if this does not ſuit another eye, then the tube muſt be puſhed in or pulled out till the object appears diſtinct.

3. The apparent magnitude of an object is the ſame wherever the eye be placed, but the viſible area is the greateſt when the eye is nearly at the focal diſtance of the eye-glaſs.

4. The object is always inverted.

5. The viſual angle depends on the breadth

of the eye-glaſs; for it is equal to the angle which the eye-glaſs ſubtends at the object-glaſs from E e.

There are two other circumſtances relative to the perfection of teleſcopes, which we have now to conſider; the *brightneſs* or *quantity of light*, and the *diſtinctneſs* with which objects are ſeen.

With reſpect to brightneſs, the teleſcope may be conſidered as perfect when it repreſents them as bright as they are ſeen by the naked eye, which is the caſe when the aperture of the pupil is filled by the rays which come from each part of the object after being tranſmitted through the teleſcope; ſo long as a teleſcope furniſhes a ſufficient quantity of rays to fill the aperture of the pupil, no greater brightneſs can be deſired, for a greater quantity would be uſeleſs. But as the ſize of the pupil varies, it has been uſual, in conſidering this ſubject, to conſider it of about $\frac{1}{10}$ of an inch diameter: when you conſider that the light of the ſun is reckoned to exceed that of the moon 300,000 times, you will eaſily perceive that a ſmall diminution of light is not of any great conſequence. Let us, however, examine the rays tranſmitted by the teleſcope, and compare them with the aſſigned diameter of the pupil; this will be clearer by attending only to one point of the object, that, for inſtance, which coincides with the axis of the teleſcope.

1. The object being at an infinite diſtance, the rays which fall upon the ſurface of the object may be conſidered as parallel to each other; therefore all the rays which come from the center of the object will be contained between the lines e P, e P, parallel to the axis E A, *fig.* 15, *pl.* 6. All theſe rays taken together are named the pencil of rays, which fall upon the object-glaſs, and the thickneſs of this pencil is equal to the aperture of the object-glaſs, whoſe diameter is P A P.

2. This cylindrical pencil of rays is changed into a conical one P F P by the object-glaſs; after having croſſed at the focus F, the rays proceed and form another cone, the apex of which is at the focus, and the baſe is the eye-glaſs. Now it is evident, that the baſe of the cone m m is as much ſmaller than the pencil P P, as the diſtance F B is ſhorter than the diſtance A F.

3. Now the rays F m, F m, after paſſing through the eye-glaſs, again become parallel to each other, and form the pencil n o, n o, which enter the eye, and paint thereon the image of that point from which they originally proceeded.

4. Every thing turns now upon the ſize of the pencil of rays n o, n o, which enters the eye; if the diameter thereof is equal or greater than the aperture of the pupil, it will be filled, and the object will be ſeen with all poſſible brightneſs.

5. But if the ſize of this pencil be much ſmaller than that of the pupil, it is clear that the repreſentation would be obſcure, which is a great defect in any teleſcope; to prevent which, the laſt pencil of rays ſhould be rather more than $\frac{1}{20}$ of an inch in diameter, though it would be better if it was nearly $\frac{1}{10}$ of an inch.

6. Now it is evident, that the ſize of the laſt pencil of rays depends on the ſize of the firſt by which it is formed, which is eaſily determined; for we have only to ſee how much ſmaller n n is than P P, the aperture of the object-glaſs. Now P P is to n n as A F to B F, on which the magnifying power depends; therefore the magnifying power ſhews how much larger the pencil E P, E P, is than the pencil n o, n o.

7. From hence it is evident, that the aperture of the object-glaſs ſhould be increaſed in proportion as the magnifying power is augmented; con-

ſequently if this proportional diameter cannot be given to the object-glaſs, the teleſcope will be defective.

Opticians have eſtabliſhed, as a general rule, that the aperture of a lens ſhould always be ſmaller than half it's focal diſtance.

Diſtinctneſs of expreſſion is confeſſedly the moſt important article in the nature of teleſcopes, and to attain it, has exerciſed the genius, and called forth the abilities of a Newton, Dollond, Euler, D'Alembert, &c.

You may remember that I aſſumed as a principle, that a convex lens united in one point the image of all the rays proceeding from any given point of an object. If this was rigorouſly true, the images formed by lenſes would be as well terminated, and as perfectly defined, as the object itſelf.

But this principle is only true to a certain degree, and with reſpect to thoſe rays that are near the center of the lens; for the rays which paſs through the glaſs at a diſtance from this center are not collected in the ſame point with thoſe which paſs through the middle, and from this double image great indiſtinctneſs ariſes.

To render this more clear, we muſt again have reference to a diagram. Let P P, *fig.* 7, *pl.* 7, be a convex-glaſs; E e an object ſituated on the axis thereof; E the point coinciding with the axis, and ſending out rays E M, E N, E A, E M, E N, on the ſurface of the glaſs. We have to conſider how the direction of theſe rays is changed by the lens.

1. The ray E A paſſing through the middle of the glaſs is not refracted, but proceeds in the ſame rectilinear direction A B E.

2. The rays E M, E M, which are very near to E A, are only refracted in a ſmall degree, but ſo as to unite ſomewhere, as at F, which point of

union we have conſidered as the focus of the lens.

3. The rays EN, EN, which are further from the axis, or nearer the edge of the glaſs, are refracted ſomewhat differently, ſo as to meet at G nearer the lens than the point F, forming a ſeparate image Gg.

4. This circumſtance concerning the rays which fall upon the lens at a diſtance from the center, and there forming another image of the ſame point, ſeparate from that which is formed by the rays that paſs near the center of the lens, though I have not noticed it to you before, merits conſiderable attention.

5. From hence you will perceive, that the firſt image Ff is formed only by the union of thoſe rays which are very near the middle of the glaſs, and that a ſucceſſion of images is formed by the rays that are more and more removed from the axis, till at laſt you come to thoſe which fall near the edge of the lens, which form the image Gg.

6. An indefinite number of images are therefore formed between Ff and Gg, by the rays that fall upon the ſurface of the lens between the axis and the edge thereof.

7. This ſucceſſion of images is termed the *aberration ariſing from the ſphericity* of the glaſs, or the diffuſion of the image; and it muſt be evident to you, that when theſe rays enter the eye, the viſion obtained thereby of the original point muſt be confuſed and indiſtinct; but if the ſpace FG could be reduced to the point F, there would be no confuſion or want of diſtinctneſs.

8. This diffuſion or diſperſion of the rays is greater in proportion as the arcs PAB, PBP, are larger ſegments of their reſpective circles; and you will perceive from thence, that very thick and convex lenſes are to be rejected; thus, in this figure,

where the arcs PAP and PBP are the fourth part of the whole circumference, the confuſion would be inſupportable.

9. Some authors who have written upon this ſubject, ſay, that the arch forming the lens ſhould not contain more than 20 degrees of it's reſpective circumference.

10. But if the lens be deſigned for the object-glaſs of a teleſcope, it muſt be formed of an arc containing fewer degrees; for though the diſperſion of the rays may be inſenſible in itſelf, the magnifying power multiplies it as often as the object itſelf: hence the greater the magnifying power, the ſmaller the number of degrees that ſhould be embraced by the object-glaſs.

When the diſperſion of the rays is very great, it may be leſſened by covering the edge of the lens with an opake ring, leaving only a ſmall aperture round the center of the lens; by this means *diſtinctneſs* is reſtored, but *brightneſs* is diminiſhed, and as much is loſt on one hand as is gained on the other; the more ſo as every increaſe in magnifying power requires a proportional increaſe of aperture. Opticians have therefore with much pains and aſſiduity endeavoured to diſcover ſome means of correcting this diſperſion, without leſſening the aperture of the object-glaſs.

The focus of the rays which paſs through the middle of a convex lens, is, as you have ſeen, further from the lens than the focus of the rays which paſs near the edge of the glaſs. Now it has been obſerved by opticians, that a concave lens produces a contrary effect; they have conſequently inveſtigated this ſubject, in order to ſee whether they could not combine a concave with a convex lens, ſo as to correct or deſtroy this aberration, while the compound lens produced the ordinary effect of a ſimple object-glaſs. We have already ſhewn you, that concave lenſes are conſidered according to their focus as well as convex lenſes, but with this difference, that the focus of a concave lens is *virtual* or *imaginary*, and falls before the lens, while that of the convex is *real*, and falls behind the lens. Theſe circumſtances being conſidered, opticians reaſoned in the following manner.

1. If you place a concave lens behind a convex one of the ſame focal diſtance, the rays that would have been united in it's focus are ſo refracted as to be rendered parallel to each other, as they were before they entered the glaſs.

2. In this caſe the concave lens deſtroys the effect of the convex, and the rays go on in their original and natural order.

3. If the focal diſtance of the concave lens is ſmaller than that of the convex, the effect would be greater, and the rays rendered diverging. Thus the incident parallel rays, L M, L A, L M, *fig.* 8, *pl.* 7, paſſing through the glaſſes M P, Q Q, will go on diverging in the direction N O, B F, N O. Theſe two glaſſes therefore, when combined, produce the ſame effect as a ſingle concave, that would give to parallel rays the ſame degree of divergence. Two glaſſes combined together, of which the concave has a ſmaller focal diſtance than the convex, are equivalent to a ſingle concave glaſs.

4. But if the concave lens Q Q, *fig.* 9, *pl.* 7, has a longer focal diſtance than the convex lens P P, it will not even render the rays parallel that the convex lens would unite at it's focus F, but it will however ſo far leſſen their convergence, that inſtead of meeting at E they will unite at O, a point further from the lens.

5. The combined lenſes in this inſtance produce the ſame effect as a ſingle convex lens, whoſe focus would be at O. It is evident then, that it is poſſible to vary infinitely the combination of two

lenſes, the one convex and the other concave, ſo that the combined lenſes may be equivalent to any given convex lens.

6. Such a combined lens may be applied to a teleſcope inſtead of a ſingle lens, and the effect with reſpect to magnifying power will be ſtill the ſame; but the degree of diffuſion or diſperſion in the rays will be very different; it may be greater or much leſs than in a ſingle lens: in the laſt caſe the double object-glaſs will be far preferable to a ſingle one.

7. But what is ſtill more advantageous, it is poſſible ſo to arrange them, that this diſperſion may be deſtroyed. Calculation diſcovers theſe combinations, but the hand of the artiſt is not equal to the execution.

The combination of two lenſes in the manner that I have here deſcribed, forms what is called a *compound object-glaſs*; the end to be attained is, that the rays which paſs through the lens, as well thoſe at the edge as thoſe at the center, may be united in a ſingle point, and form only one image, without ſuch a diſperſion of the rays as takes place in a ſingle object-glaſs.

Many are the advantages that would be derived from ſuch a combination; the object would appear more diſtinct and better terminated, becauſe the viſion would not be confuſed by that mixed ſucceſſion of images produced by a ſingle object-glaſs. This diſperſion of the rays is one of the principal reaſons which forces us to make uſe of very long teleſcopes, in order thereby to diminiſh the effect of the diſperſion; but if this diſperſion was entirely deſtroyed, much ſmaller ones might be uſed, that ſhould be productive of the ſame effect.

It will be neceſſary to obſerve to you here, that the ſides or faces of the lenſes may be formed in different ways, almoſt *ad infinitum*, and yet the focus remain the ſame; this is effected by forming the ſides of equal or unequal radii, as will be evident by conſidering an example. Let us ſuppoſe then a convex lens, whoſe ſides have been formed on a tool of 24 inches radius, conſequently each face is the ſegment of a circle of 24 inches radius; it will be equally convex on both ſides, and be of 24 inches focus, as commonly eſtimated; but as the focus depends on the refraction, it varies according to the denſity of the glaſs; generally the focal point is nearer the lens than the radii of the face, ſometimes a tenth or twelfth part, ſo that the lens that we have ſuppoſed to be ground on a tool of 24 inches radius will have it's focus at 22 inches.

By making the ſurfaces unequal, an infinite variety of lenſes may be formed, that ſhall all have the ſame focus; *ex. gr.* if one face be taken of a ſmaller radius than 24 inches, the other muſt be taken of a longer, the one thus compenſating for the other. The following table exhibits a view of ſome of the varieties with which the two faces of a lens may be worked, and yet produce the ſame effect.

Glaſſes.	Radius of 1ſt face.	Radius of 2d face.
1	24	24
2	21	28
3	20	30
4	18	36
5	16	48
6	15	60
7	14	84
8	13	156
9	12	infinite.

In the laſt or ninth form the radius is only 12, the half of 24 inches; but the other face the ſegment of a circle, whoſe radius is infinite, and therefore may be conſidered as a ſtrait line; and therefore this lens would be a plano-convex.

If you are deſirous that one of the faces be formed of a ſmaller radius than 12 inches, the other face muſt be concave, and the glaſs will be convexo-concave, or what is termed a *meniſcus*. The following table is a ſpecimen of figures for this form:

Meniſcus.	Rad. of 1ſt face.	Rad. of concave.
10	11	132
11	10	60
12	9	36
13	8	24
14	6	12
15	4	6
16	3	4

You have here then ſixteen different kinds of lenſes, whoſe foci will all be at the ſame diſtance or point. If the focus only were conſidered, it would be indifferent which of theſe were employed; yet it is not ſo with reſpect to the diſperſion of the rays, for in this reſpect they differ conſiderably; it is much more in ſome than in others. Amongſt theſe, that of the ſeventh kind is one of thoſe where the diſperſion is leaſt, being nearly one half leſs than it would be if the lens were equally convex on both ſides; and it is therefore of an advantageous figure for a ſingle object-glaſs.

From what has been ſaid, you perceive, that in order to correct the aberration that ariſes from the ſphericity, it is neceſſary to reſolve a problem which will diſcover what are the proper radii for the two ſurfaces of a lens, ſo that the diſperſion of the rays may be annihilated; the ſolution requires a cona conſiderable knowledge of the more profound parts of geometry, and therefore does not come within the compaſs of theſe Lectures; enough, however, has I hope been ſaid to render the ſubject clear to you, and to point out the neceſſity and nature of theſe inveſtigations.

There is ſtill another *aberration* to be corrected, another cauſe of *diſperſion* in the rays to be counteracted or deſtroyed; this ſeems more important, and more difficult to be cured, as it does not depend on the *glaſs*, but on the nature and properties of the *rays of light*. You no doubt remember what I have already told you reſpecting the variety in the rays, according to the different colours they occaſioned, that is, that they were of different degrees of refrangibility; thus, that the red-making rays were the leaſt refracted, and the violet-making rays the moſt refracted, all the other rays falling within theſe two extremes.

Thus when a beam of light falls obliquely upon a piece of glaſs A B C D, *fig.* 10, *pl.* 7, inſtead of proceeding in the ſame direction P Q, it is not only refracted but ſeparated into ſeveral rays P t, P S, P r, P v, of which the firſt P t, that is the leaſt refracted, repreſents the red-making ray, and the laſt P v, the violet-making ray. Their divergence is indeed much leſs than that which is repreſented in this diagram, but ſufficient to become ſenſible.

From this difference in the refrangibility of the rays, ariſe various phenomena with reſpect to dioptric glaſſes, among which are the following:

1. Let P P, *fig.* 11, *pl.* 7, be a convex lens at a conſiderable diſtance A O, from the object O o, to determine the image formed by the lens, without taking into conſideration the aberration already diſcuſſed; or what comes to the ſame thing, only

conſidering the rays that paſs through the middle of the lens.

2. Let us ſuppoſe that the object O o be red, and the rays proceeding therefrom will be all red-making rays, and will form ſomewhere a red image R r of the object, and R will be the focus of the red-making rays, or thoſe which have the leaſt refraction.

3. But if the object O o be violet, the rays will be more refracted, and the image V v will be nearer the lens, and the point V will be the focus of theſe rays.

4. If the object be of any of the intermediate colours between theſe two, the image will fall between R and V.

5. But if the object is not of an homogeneous colour, (or is white,) as is the caſe in moſt bodies, the different kinds of rays are ſeparated by refraction, and each kind forms an image apart; that formed by the red-making rays will be found at R r, and that by the violet at V v, and the ſpace R V will be filled by images of the intermediate colours.

6. The glaſs P P will repreſent an indefinite number of images of each object O o formed in the ſpace R V, and ſituated in the order of the priſmatic colours.

7. Each of theſe images will be diſtinct in itſelf, but taken together productive of a very ſenſible confuſion.

8. Here then is another ſpecies of diſperſion totally independent of that which we have already treated of, and tinging each image with a particular colour.

9. This diſperſion depends conſiderably on the focal diſtance of the lens; being about $\frac{1}{28}$th part; when the focal diſtance is 28 feet, the ſpace R V

is about 1 foot. If the lens was of 56 feet focus RV would be about 2 feet.

I have now explained to you a ſecond ſource or cauſe of indiſtinct or imperfect viſion; namely, that which ariſes from the different refrangibility of the rays: which requires a different mode of correction from the former error, which I ſhall treat of when we come to ſpeak of ACROMATIC TELESCOPES; and only ſhew here, how the error may be in a degree corrected, by the diſpoſition of the eye-glaſſes.

1. It is certain, that the object-glaſs forms an infinity of images of each object, ſucceſſively ranged in the ſpace of diffuſion, each of which tinged with it's proper colour.

2. Each of theſe images becomes an object, with reſpect to the eye-glaſs, with it's reſpective colours; and if, inſtead of one eye-glaſs, more are uſed, the ſame thing ſtill takes place.

3. Let us therefore, in this diagram, conſider the laſt images that the teleſcope forms for the eye at O, and let Rr be the red image, and Vv the violet; the other colours falling within this ſpace, according to their different degrees of refrangibility. The lenſes are not exhibited in the figure, becauſe we are only to conſider the manner in which the images are ſeen by the eye, ſuppoſing the diſtance from the eye to them to be very great.

4. All theſe images, together with the intermediate ones, are ſituated on the axis ORV of the teleſcope, and terminated by a ſtrait line rv, that we may call the terminator of all the images.

5. According to the repreſentation in the figure, the red image Rr is ſeen by the eye at O, under the angle ROr, which is larger than the angle VOv, under which the violet image Vv is viewed; the violet rays which enter the eye, are therefore mixed with the red rays which proceed from the part Rr of the image Rr; and, conſe-

quently, there is a very great confuſion of the images.

6. But the ray O r not being mixed with the others, the extremity or edge of the image will be red; but will ſoon after be mixed with the other colours, forming the iris, which is ſo common in other teleſcopes. If the largeſt image was the violet, the confuſion would be as great as before, with only this difference, that the extreme edge would be violet, not red.

7. Much of the confuſion will depend, therefore, on the poſition of the terminator r v; and from the various ſituations that may be given to it, this confuſion will be ſometimes greater, and ſometimes leſs.

8. Suppoſe that the images were ſo arranged, that the terminator v r paſſed directly into the eye by a ſingle ray v r O; then the extremities of the image, and all the points which anſwer to one point in the object, would form only one point in the eye, and the point of the object would be repreſented diſtinctly.

9. This advantage is to be obtained when the terminator, being prolonged, paſſes directly into the eye; and ſuch a poſition is to be ſought for in the arrangement of the eye-glaſſes.

Before we enter upon acromatic teleſcopes, I ſhall endeavour to explain the nature of teleſcopes with three eye-glaſſes, in which the image is ſeen erect.

1. Let the four glaſſes A, B, C, D, *fig.* 7. *pl.* 8, in the tube repreſent the teleſcope; the glaſs A, directed towards the object, is called, as we have before ſaid, the object-glaſs, the three others the eye-glaſſes: the four glaſſes are convex.

2. Let us conſider the effect produced by each eye-glaſs, the object o O being ſuppoſed at a conſiderable diſtance. The object-glaſs will form an image of the object at P p; it's focus; the ſize of

this image may be found from o, through the middle of the glaſs A. I have not drawn this line, in order to avoid confuſion from a multiplicity thereof.

3. The image Pp now becomes an object, with reſpect to the eye-glaſs B, which is ſo placed that the interval Bp is equal to the focus of B; by this the ſecond image is tranſported to Qq, and is inverted, as well as the firſt Pp; it's ſize is determined by a line drawn from the middle of the glaſs B, through p.

4. The interval AB, between theſe two lenſes, is equal to the ſum of their foci, forming the aſtronomical teleſcope already explained; the image being inverted, and magnified as many times as AP exceeds BP; but inſtead of the eye-glaſs, another lens C is placed behind B; with reſpect to this lens, the image Qq becomes the object, which being at a conſiderable diſtance, the lens C forms an image thereof at it's focus r.

5. The image Qq being inverted, that of Rr will be inverted, and terminated by a right line drawn from q through the middle of the glaſs C, which will paſs by r; conſequently, the three lenſes A, B, C, give the image of the object Oo at r, and this image is upright.

6. You have now only to place the third lens ſo that the interval DR be equal to the focus. By this the image will be again, as it were, transferred to an infinite diſtance Ss, of which the ſize will be determined by a ſtrait line drawn through the middle of the glaſs d, and paſſing by the extremity of the image r, and the image Ss will be ſeen by the eye, inſtead of the object Oo.

7. It is eaſy now to determine how many times a four-glaſſed teleſcope magnifies the object. For this purpoſe, you have only to conſider the lenſes in pairs, A, B, and C, D; each of theſe, taken ſeparately, being an aſtronomical teleſcope. The

firſt pair of glaſſes, A and B, magnify the object as many times as the focal diſtance of A exceeds that of B, and juſt ſo many times the image Q q exceeds the object O o.

8. Q q being now conſidered as the object, is magnified as many times as the focus of C exceeds that of D; theſe two powers added together, give the total magnifying power of the teleſcope.

Fig. 11, *pl.* 4, is a perſpective view of a model deſigned to illuſtrate the nature of a four-glaſs teleſcope, which ſhews the objects in their true poſitions; the rays of light are repreſented by ſilk ſtrings of different colours, ſo that their progreſs is eaſily traced; A B C the object, D E the object-glaſs, I K, M N, Q R, the eye-glaſſes, ſo placed that the foci of D E and I K meet in G. Thoſe of I K and M N may meet at L, and thoſe of M N, Q R, may meet in g. From the progreſs of the rays, you perceive that the image at H T is inverted, that the rays proceed from I K in a parallel direction, croſſing at L, from whence they go on to M N, paſs through it, and are thereby converged into a focus, and form a ſecond image f g h erect, which image will be viewed by the eye in the focus of the eye-glaſs Q R.*

SUMMARY VIEW OF THE PROPERTIES OF THIS TELESCOPE.

The magnifying power is in proportion as the focal diſtance of the object-glaſs is to the focus of the eye-glaſs.

It ſhews the object erect, but not ſo bright as in the teleſcope, with two lenſes; becauſe the other eye-glaſs reflects a conſiderable quantity of light which is loſt.

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* At *fig.* 12, *pl.* 4, another model is repreſented, formed with lenſes, to try experimentally the places of the images.

The viſible area depends on the breadth of the eye-glaſs.

The brightneſs of an object ſeen through a given teleſcope, is greater in proportion as the aperture of the object-glaſs is greater.

If the aperture and focus of the object-glaſs remain the ſame, an object appears brighter or fainter according to the greater or leſs focal diſtance of the eye-glaſs, that is, according to the magnifying power; for the ſame quantity of light being ſpread over a greater or ſmaller ſurface, renders the image obſcure or brighter.

ON THE CONSTRUCTION AND MAGNIFYING POWER OF TELESCOPES MADE WITH SEVERAL EYE-GLASSES.

In this diagram, *pl.* 8, *fig.* 1, A is the firſt, B the ſecond, C the third, D the fourth, E the fifth eye-glaſs, and O the object-glaſs. DA the axis of the teleſcope is alſo the common axis of all the lenſes; I m w an oblique pencil paſſing through the object-glaſs, and falling on the extreme edge of the lens, which is next the object-glaſs. O w is the axis of the pencil (repreſented by a black line), ſhewn as refracted ſucceſſively into the lines w v, v t, t s, s r, r α, cutting the axis of the teleſcope (when produced) in the points ϵ, δ, γ, β, α, reſpectively. O is the focus of this oblique pencil after refraction at the object-glaſs; e, d, c, b, the ſucceſſive foci of this pencil after refraction at each of the eye-glaſſes. From each of theſe foci draw perpendiculars to the axis of the teleſcope, and theſe perpendiculars, o x, e g, d h, c z, b y, will be places and magnitudes of ſucceſſive images either *real* or *imaginary*; *real* when the image is actually formed, ſo that it would be viſible if the rays were received upon a white paper; *imaginary* when the rays after refraction proceed as if they came from or tended to ſuch an image, although this image is not actually formed. *When the image is real, the rays of each pencil actually come to a focus.* When it is imaginary, theſe rays after refraction diverge from or converge towards ſuch a focus, but are never actually united.

Although each lens has it's image either real or imaginary, yet there are only two real ones in the conſtruction here delineated, the firſt e g inverted, the ſecond b y upright.

When the number of real images is even, the object will be ſeen upright; when that number is odd, the object is inverted. Galileo's teleſcope, in which there is no real image, ſhews the object upright; it cannot therefore be applied to inſtruments in which croſs wires are neceſſary, becauſe the wires cannot be ſo placed as to be ſeen diſtinctly together with the object.

All that is eſſential to the conſtruction of teleſcopes is, only that the rays of the ſame pencil, which enter parallel, ſhould likewiſe emerge parallel, for the object will in that caſe be ſeen diſtinctly; the intervals and focal lengths therefore of all the lenſes, except one, may be aſſumed at pleaſure, from whence that one muſt be determined. This aſſertion of moſt writers on optics is true, if nothing elſe be attended to but the courſe of a few rays coming from a ſingle point in the axis of the teleſcope, and it be only required that the middle of the object be ſeen diſtinctly; but the caſe is very different, if it be required that all parts of the object ſhould be ſeen as far as may be equally diſtinct, for then the aberration of the extreme pencil in paſſing through the eye-glaſſes muſt be taken into conſideration; and the number, place, and focal lengths of the eye-glaſſes, muſt be ſuch as may leſſen at leaſt, if not remove theſe aberrations.

It may be obſerved, that generally in any ſingle lens, the greater the focal length, and the leſs the aperture, the leſs will be the aberration of the refracted rays. That conſtruction is therefore (*cæteris paribus*) the beſt, in which the eye-glaſſes have large focal diſtances and ſmall apertures; thoſe eſpecially that are concerned in forming the laſt image. As to the ſingle lens by which the laſt image is viewed, it may be allowed to have a ſhort focal length, particularly if it's aperture may be contracted; for though this lens magnifies the faults already made in the laſt image by the other glaſs, it does not create new faults.

Among the various ſorts of teleſcopes made with convex lenſes, and deſigned to ſhew the object upright, thoſe with four or five glaſſes are preferable to thoſe with fewer. The fewer lenſes there are in the eye-tube, the greater muſt be the refraction of the extreme pencils at each lens, ſuppoſing the ſum of all the refractions, or the whole change in the direction of the pencils, to be the ſame. Now though the number of refractions is increaſed, yet if the quantity of each refraction be proportionably diminiſhed, the ſum of all the aberrations in theſe pencils will be greatly leſſened; and the loſs of light, by paſſing through more glaſſes, will be very inconſiderable.

Agreeable to this principle, it is found, that an object ſeen through two double convex lenſes, both of a ſize, and put cloſe together, appears diſtincter near the edges of thoſe lenſes, than if ſeen through one lens whoſe focal length is equal to that of the other two ſo combined together: likewiſe two equal plano-convex lenſes ſhew an object diſtincter at their edges when combined with their convex ſides touching each other, than contrariwiſe. Thus then the aberrations from the figure of the eye-glaſſes may be leſſened, by increaſing the number and diminiſhing the quantity of the ſeveral refractions.

The lens E, which intercepts the rays before the firſt image is formed, diminiſhes the magnifying power, but improves the diſtinctneſs of the teleſcope, by leſſening the diameter of the apertures of the deep lenſes D and C. The extreme pencil O W, which diverges from O, being refracted by this lens into W V, is made to converge towards the axis of the teleſcope, ſo that if produced it would meet at ε. By this means the ſemidiameter of the lens D is reduced to D V, whereas if the firſt real image had been formed at O x by the object-glaſs only (the extreme pencil O o in that caſe continuing to diverge), the ſemidiameter D V muſt have been greater than the image O x, to take in the ſame field.

The rays belonging to this and every other pencil which diverge from e g, the firſt real image muſt be made to converge again by the two lenſes D and C, that a ſecond real image may be formed upright. Two lenſes are employed for this purpoſe, becauſe the errors in the ſecond image will be leſſened by their contrary refractions; ſuppoſing therefore their convexities equal, and that the rays of this pencil (refracted into v t) go parallel or nearly ſo between the lenſes D and C, then it is evident, that the focal length of D muſt be equal to the diſtance e v (=g D), or nearly ſo; therefore the lenſes D and C, having a ſhorter focal length, will by no means admit of an aperture, whoſe ſemidiameter is greater than o x. It may be further obſerved, that this pencil, which at firſt diverged from the axis of the teleſcope, in the angle w O E and v δ D, by the interpoſition of the lens E, this change is made at two refractions (at w and v), which muſt otherwiſe have been made by the refraction of the lens D only.

In like manner, the other lens B, which intercepts the rays juſt before the ſecond real image is formed, diminiſhes indeed the magnifying power, but makes the teleſcope more diſtinct. The extreme pencil we have been conſidering, after refraction at t by the lens c, diverges from the axis of the teleſcope, proceeding as if it came from the point γ; but being refracted by the lens B into sr, is made to converge, ſo that if produced it would meet the axis of the teleſcope in β. This leſſens the laſt image, reducing it from c z to b y; and as it is this image which is viewed by the eye through the eye-glaſs A, the interpoſition of the lens B leſſens the magnifying power, the eye-glaſs A remaining the ſame. The extreme pencil S v thus converging upon the eye-glaſs A, the ſemidiameter of this glaſs will be reduced to A r; whereas, had the lens B not been interpoſed, (the extreme pencil t s c continuing to diverge from γ) the ſemidiameter of this eye-glaſs muſt have been greater than the image c z, to take in the whole field. As a ſmall aperture of the eye-glaſs A is ſufficient to take in the whole field when the pencils thus fall upon it converging, this lens may be allowed to have a ſhorter focal length, and thus compenſate for the loſs of magnifying power by the interpoſition of the lens B, without increaſing the aberration of the extreme pencils.

You may prove this experimentally by taking out the ſecond eye-glaſs, then drawing out the tube to make the teleſcope diſtinct again, and you will find the magnifying power increaſed, the field diminiſhed, and perhaps indiſtinct near the edges.

OF ACHROMATIC TELESCOPES.

To render this ſubject plain and clear, I ſhall recal to your mind a few of thoſe principles which we have already explained. Thus you know that a ray of light, refracted by paſſing through mediums of different denſities, is at the ſame time proportionally divided or ſpread into a number of parts, called homogeneal rays, each being the exciting cauſe of a different colour; and that theſe rays after refraction proceed diverging.

That a ray of light paſſing obliquely from a rarer into a denſer medium, is refracted towards the perpendicular; but when it paſſes from a denſer into a rarer medium, it is refracted from the perpendicular.

That when a ray of light is refracted out of air into a given medium, or out of a given medium into the air, the ſines of the angles of incidence and refraction are in a conſtant ratio.

But light conſiſting of parts which are differently refrangible, each part of an original or compound ray has a ratio peculiar to itſelf; and that the more the heterogene ray is refracted, the more will the colour-making rays diverge, as the ſines of the homogene rays are conſtant, and equal refraction produces equal divergencies.

From hence you have alſo been ſhewn, that the rays when paſſing through a convex lens, inſtead of uniting in one focus, form as many foci of different diſtances, as there are coloured rays; and that the priſmatic colours or iriſes, which appear towards the borders of convex lenſes, render the images confuſed.

The indiſtinctneſs of viſion produced by this cauſe, which is ſenſible in teleſcopes of a ſmall aperture, increaſes into ſo high a ratio upon enlarging the aperture, namely, as the cubes of the diameters, that unleſs this confuſion of colours was corrected, it would be impoſſible to increaſe greatly the power of refracting teleſcopes, without extending their length to a very inconvenient ſize.

It was known before Mr. Dollond's, that different tranſparent bodies poſſeſſed ſome a greater and ſome a leſs refractive power; and it was taken for granted, until he evinced to the contrary, that the diſperſive power of the coloured ray was in every tranſparent body proportional to it's mean refractive power; or in other words, that the refraction of the coloured rays, whatever body they paſſed through, were always in a conſtant determinate ratio to each other. Conſequently, if the diſperſion produced by a convex lens, were counteracted by another lens or medium of a concave form, that the refraction would alſo be totally deſtroyed; and that this would be the event, if the two lenſes were even made of the ſame matter. Upon this ſuppoſition, it was impoſſible ever to correct this fault in dioptric teleſcopes.

While opticians continued to think, that equal refractions would, in every ſort of medium, neceſſarily produce equal divergencies, and that conſequently equal and contrary refractions would deſtroy each other, and that the divergency of colour from one refraction would be corrected by the other, there could be no poſſibility of producing any refraction that would not be affected by the different refrangibility of light. For, however a ray of light might be refracted backwards and forwards by different media, provided it was ſo done that the emerging ray was parallel to the incident one, it would always be white or colourleſs; but if it came out inclined to the incident ray, it would diverge and be ever after coloured.

This erroneous ſuppoſition was countenanced by an experiment of Sir I. Newton, of placing two priſms, one made of glaſs contained within a priſmatic veſſel, filled with water, in ſuch manner that the rays of light which were refracted by the priſm of glaſs ſhould paſs through and be refracted in a contrary direction, and in as great a degree by the water priſm; by which means he relates, that light thus reſtored to it's original direction was white and free from colours.

"In the year 1757, Mr. John Dollond repeated this famous experiment of *Newton*, of refracting a ray of light through priſms of glaſs and water, placed with their refracting angles in oppoſite directions, and ſo proportioned to each other that the ray after theſe oppoſite refractions emerged parallel to the incident ray. According to the Newtonian doctrine, there ought here to have been no divergency of the heterogeneal rays, and *no colour* produced by theſe equal and oppoſite refractions.

But this was *not* the reſult of the experiments; the ray was very ſenſibly coloured. Mr. Dollond, finding that oppoſite refractions produce colour notwithſtanding the paralleliſm of the incident and emergent ray, concludes, that by properly adjuſting the angles, he might effect an inclination of the refracted to the incident light, without any colour or divergency. Experiment proved his reaſoning to be juſt.

It may be proper to obſerve here, that thoſe media are ſaid to have the ſame *mean refractive denſity*, which, under equal obliquities of incidence, equally refract the mean refrangible ray; and two media are ſaid to have the ſame *diſperſive power*, which produce an equal inclination of rays of the ſame colour to the mean refrangible ray, when the whole refraction of the mean refrangible ray is equal in both.

Let the vertex of a flint glaſs priſm, the refracting angle of which is equal to 23° 40′, be applied to the baſe of a crown glaſs priſm, the refracting angle

angle of which is equal to 25°; a ray of ſolar light will paſs through the priſms when their ſurfaces are contiguous, but the emergent ray will be coloured. *

The ray is ſuppoſed to fall perpendicularly upon the ſurface of the priſm, whoſe refracting angle is the greateſt.

The poſition of the priſms in this experiment is ſuch, that the effects of refraction upon the paralleliſm of the homogeneal rays paſſing through them are contrary to each other, and conſequently if they were equal the rays would emerge parallel. But the flint priſm, by it's greater diſſipating power, more than counteracts the ſeparation of the rays cauſed by their paſſage through the firſt priſm, which was equal 38 ½ minutes; and inverting the order of the colours, cauſes the red and violet rays to emerge, inclined to each other at an angle of 12 ½ minutes, ſufficiently great to produce a ſenſible tinge of the priſmatic colours in the emergent rays.

Every thing remaining as in the laſt experiment, let the vertex of a crown glaſs priſm, the refracting angle of which is 10°, be applied to the baſe of the flint priſm. If a ray of ſolar light paſſes through the three priſms, when their ſurfaces are contiguous, the emergent ray will deviate about 5° 37′ from the courſe of the incident ray, but will be colourleſs.

In this caſe the two crown glaſs priſms refracting the ray in the ſame direction, cauſe it to deviate from the courſe of the incident ray about 5° 37′ more than the deviation in the contrary direction ariſing from refraction through a flint priſm.

But the flint priſm, by it's greater *diſſipating* power, exactly counteracts the ſeparation of the rays cauſed by refraction through the other two priſms, ſo that the homogeneal rays emerge at length parallel, and of courſe colourleſs.

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* Atwood's Analyſis of a Courſe of Lectures, p. 164, 165.

Now this was what was wanted; for you have ſeen, that the difficulty which chiefly impeded the improvement of teleſcopes was, ſo to refract a ray while it deviated conſiderably from it's original courſe, that the diſperſion of the homogeneal rays might be counteracted, and that by this means they might all emerge parallel, and of courſe free from colour; and this is, you perceive, effected by a combination of tranſparent ſubſtances, the refracting and diſſipating powers of which are different.

In this experiment the rays of mean refrangibility emerge at an angle of refraction equal to 16° 57′.

If a ſolar ray impinged upon the ſurface of the priſm laſt applied at an angle of incidence equal to 16° 57′, the angle of diſſipation after emergence into air would be equal 12 ½°.

But it was ſhewn in the former experiment, that the diſſipation of the rays emerging from the two priſms was equal 12 ½, for which reaſon (and on account of the contrary poſition of the priſms) the red and violet rays emerging, inclined to each other at an angle of 12 ½ from the two priſms, and falling upon the third will be refracted out of it colourleſs.

It appears then that two kinds of glaſs are neceſſary for achromatic teleſcopes, one of which ſhall poſſeſs as ſmall, and the other as great diſperſive powers, relatively to their mean refracting ray, as can be procured.

The difference of glaſs in this reſpect depends on the quality of the ingredients employed in their compoſition.

Crown-glaſs, which is compoſed of ſand, melted by means of the aſhes of ſea-weeds, barilla, or kelp, both which fluxes are known to conſiſt of vegetable earth, alkali, and neutral ſalts, is found to give the ſmalleſt diſperſive power.

Plate-glaſs, which is compoſed of ſand melted by means of fixed alkali, with little or no vegetable earth, gives a greater diſperſive power.

The diſperſive power of *flint-glaſs* is much greater than either of the other, and this conſiſts of ſand melted by a mixture of minium and fixed alkali. It is probable therefore, that minium and other metallic calces give the greateſt diſperſive power, and that alkalis give more than vegetable, and probably other earths.

Let a crown-glaſs priſm, whoſe refracting angle is 30°, be applied contiguous to a priſm of flint-glaſs, whoſe refracting angle is 19°; with the vertices of the priſms in oppoſite directions, a ſolar ray being refracted through them will deviate from the courſe of the incident ray, but will not be ſeparated into the coloured rays.

Here it appears, that the two priſms operate equally upon the paralleliſm of the homogeneal rays paſſing through them, and that as theſe effects by the poſition of the priſms tend to correct each other, the homogeneal rays, after being refracted through them, emerge parallel and colourleſs.

Mr. Dollond next conſidered, that as a ray might be refracted free from colour through a wedge, it might alſo through a lens. When an image of an object is formed by a convex lens, it appears coloured, owing to the diſperſion of the rays by refraction; as therefore rays can be refracted without diſperſion by priſms, he conceived that it might alſo be done by a combination of lenſes. And in this he ſucceeded, by conſidering, that in order to make two ſpherical glaſſes that ſhould refract the light in contrary directions, as in the two wedges, one muſt be concave and the other convex; and as the rays are to converge to a real focus, the exceſs of refraction muſt be in the convex lens, becauſe that makes rays converge, and the concave makes them diverge. Alſo, as the convex lens is to refract moſt, it muſt be made of crown-glaſs, as appeared from the experiments with the wedges, and the concave lens of white flint-glaſs. Farther, as the angle of diſperſion varies inverſely as the focal length, very nearly, from the principles of optics, and the angle of diſperſion alſo varies as the diſperſing powers, therefore if the focal lengths be taken inverſely as the diſperſing powers, found from the two wedges, the angles of diſperſion will be equal, and being in contrary directions they will correct each other, and the different refrangibility of light will be removed.

Upon this principle, Mr. Dollond was enabled to make a combined lens to form an image free from colour, and therefore brought to perfection the refracting teleſcope, making it repreſent objects with great diſtinctneſs, and in their true colours. Inſtead of forming the object-glaſs with one convex lens of crown and one of flint-glaſs, two convex lenſes of crown are uſed, and the concave one of flint put between them. This conſtruction of the object-glaſs tends alſo to correct the error ariſing from the ſpherical form of the lens; for as the rays at the edge of the convex lens tend to a focus nearer to the lens than thoſe at the middle, the concave lens, which makes the rays at the edge diverge more than thoſe at the middle, will counteract the above effect, and bring the rays at all diſtances from the center of the lens to a focus more nearly together; and by a proper adjuſtment of the foci, the diffuſion of rays at the focus may be rendered inconſiderable. Teleſcopes thus conſtructed are called *achromatic*.

This diſcovery of Mr. DOLLOND was ſo extraordinary, and ſo contrary to the beſt eſtabliſhed principles, that it was not believed at firſt by Mr. EULER. At length, however, Mr. ZICHER, of Peterſburg, made experiments ſimilar to thoſe of Mr. Dollond, and convinced Mr. Euler that it was true. He alſo ſhewed, that it is the lead which is uſed in ſome compoſitions of glaſs, which produces the extraordinary property of augmenting the diſperſion of the extreme rays, without ſenſibly changing the refraction of the mean.

Mr. Euler, in a paper read at the academy of ſciences at Berlin in 1764, was candid enough to own he did not at firſt credit the account, and thereby gave to Mr. DOLLOND the credit of the diſcovery. Notwithſtanding this, Mr. Delaland in his aſtronomy, and Mr. Fieſs in his eulogy on Mr. Euler, both aſcribe the invention to Mr. Euler. Mr. P. Dollond has however fully proved, that the diſcovery muſt be attributed to Mr. John DOLLOND.*

In the ſame pamphlet Mr. Dollond has ſhewn the reaſons which prevented Newton from drawing the ſame concluſions; that it aroſe from the kind of glaſs he made uſe of, ſo that his veracity remains unimpeached, and the experiments, when made with the ſame kind of glaſs, exactly correſpond with thoſe of Sir I. Newton. In his time the Engliſh were not famous for making teleſcopes; many were imported from Venice. The glaſs imported from this place was nearly of the ſame refractive quality as our crown-glaſs, but of a better colour. It is probable that Newton's priſms were made of that glaſs, becauſe he mentions the ſpecific gravity of common glaſs to be to water as 2,58 to 1, which anſwers nearly to that of crown-glaſs. Mr. Dollond made a priſm of a piece of this glaſs, and trying the experiment with it, found it anſwered very nearly to what Newton relates; the difference being only ſuch as may be ſuppoſed to ariſe from the ſame kind of glaſs made at different times.

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* "Some account of the diſcovery by the late Mr. John Dollond, which led to the great improvement of refracting teleſcopes," by Mr. P. Dollond.

OF REFLECTING TELESCOPES.

Sir John Pringle, in his diſcourſe to the Royal Society on the reflecting teleſcope, attributes the firſt thought thereof to Merſennus, who propoſed to Deſcartes a teleſcope with *ſpeculæ*, many years before Gregory's invention; though indeed in a manner ſo very unſatisfactory, that Deſcartes, who had given particular attention to the improvement of the teleſcope, was ſo far from approving the propoſal, that he endeavoured to convince Merſennus of the fallacy.

Gregory was led to the invention by ſeeking to correct two imperfections of the common teleſcope; the firſt was, it's too great length, which made it leſs manageable; the ſecond the incorrectneſs of the image. It had been demonſtrated that a pencil of rays could not be collected in a ſingle point by a ſpherical lens, and alſo that the image tranſmitted by ſuch a lens would be in ſome degree incurvated.

Theſe inconveniences he believed would be obviated by ſubſtituting for the object-glaſs a metallic ſpeculum of a parabolic figure, to receive the image, and to reflect it towards a ſmall ſpeculum of the ſame metal; this again was to return the image to an eye-glaſs placed behind the great ſpeculum, which, for that purpoſe, was to be perforated in it's center.

But as *Gregory* was endowed with no mechanical dexterity, nor could find any workman capable of realizing his invention, after ſome fruitleſs attempts he gave up the purſuit. And, probably had not ſome new diſcoveries been made in light and colours, a reflecting teleſcope would never more have been thought of, conſidering the difficulty of the execution, and the ſmall advantages that could accrue from it, deducible from the principles of optics that were then known.

But *Newton*, whoſe happy genius for experimental knowledge was equal to that for geometry, and who to theſe talents, in a ſupreme degree, joined patience and mechanical abilities, happily interpoſed and ſaved this noble invention from well nigh periſhing in it's infant ſtate.

While he was employed in endeavouring to grind lenſes of the figure of one of the conic ſections, he happened to examine the colours formed by a priſm, and having by means of that ſimple inſtrument made the ever memorable diſcovery of *the different refrangibility of the rays of light*, he then perceived that the errors of teleſcopes ariſing from that circumſtance alone, were ſome hundred times greater than ſuch as were occaſioned by the ſpherical figure of lenſes. This forced Newton as it were to fall into Gregory's track, and to turn his thoughts to reflectors. If *Newton* was not the firſt inventor of the reflecting teleſcope, he was the main and effectual inventor.

It was towards the end of 1668, or the beginning of the following year, that Newton being thus obliged to have recourſe to reflectors, and not relying on any artificer for making his ſpecula, ſet about the work himſelf, and early in the year 1672 completed two ſmall reflecting teleſcopes; one of theſe he preſented to the Royal Society, communicating at the ſame time a full and ſatisfactory account of it's conſtruction and performance, and received from them ſuch thanks as were due for ſo curious and valuable a preſent.

But how excellent ſoever the contrivance was, how well ſoever ſupported and announced to the public, yet, whether it was that the artiſts were deterred by the difficulty and labour of the work, or that the diſcoveries even of a *Newton* were not to be exempted from the general fatality attending great and uſeful inventions, *the making a ſlow and vexatious progreſs to the authors*; the fact is, that excepting an unſucceſsful attempt which the Royal Society made by employing an artificer to imitate the Newtonian conſtruction, and a diſguiſed Gregorian teleſcope, ſet up by *Caſſegrain* abroad, as a rival to *Newton*'s, and that in theory only (for it was never put in execution by the author) no reflector was heard of for near half a century after. But when that period was elapſed, a reflecting teleſcope was produced to the world of the Newtonian conſtruction, which the venerable author, ere yet he had finiſhed his much diſtinguiſhed courſe, had the ſatisfaction to find executed in ſuch a manner, as to leave no room to fear that the invention would longer continue in obſcurity.

This memorable event was owing to the dexterity, the genius, and application of Mr. Hadley, the inventor of the reflecting quadrant, another moſt valuable inſtrument. The two teleſcopes which Newton had made, were but 6 inches long, and in power were compared to a 6 feet refractor. Hadley's teleſcope was above 6 feet long, and equalled in performance the famous aerial teleſcope of Huygens, of 123 feet in length.*

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* Sir John Pringle's Diſcourſes, p. 206, &c.

It may be worth obſerving, that Sir I. Newton ſent his teleſcope to the Royal Society while his election into the ſociety was depending, and he concludes with ſaying, "that if he ſhould be elected, he would endeavour to teſtify his gratitude by communicating what his poor and ſolitary endeavours could effect, toward promoting their philoſophical deſign." Such was the modeſty of the man, who was the glory of the ſociety, of the nation, of the world.

OF THE GREGORIAN REFLECTING TELESCOPE.

The Gregorian reflector conſiſts of two concave mirrors, and two plano-convex lenſes for the eye-glaſſes.

T T T T, *fig.* 2, *pl.* 8, is a cylindrical tube; at the bottom of this a concave metallic reflector or mirror D U V F is placed; this reflector has a hole in the middle.

Towards the other end a ſmall concave mirror L is placed; this is ſupported on an arm M, which may be moved nearer to, or farther from the great ſpeculum, at pleaſure.

Theſe two mirrors are placed parallel to each other; the ſmall one is generally ſomewhat larger than the hole in the great mirror.

At the bottom of the cylindrical tube, and juſt oppoſite to the perforation in the large mirror, is a ſmall braſs tube αβδε, containing the two eye-glaſſes; at the further end of this tube is a very ſmall hole, to which the eye is to be applied.

The conſtruction being underſtood, we may proceed to explain the optical effect of this inſtrument.

1. The open end of the cylindrical tube being ſet directly towards the object, which being ſup-

poſed to be diſtant, the rays proceeding therefrom may be conſidered as parallel to each other; and being reflected back by the large concave ſpeculum, they will form an image of the object at it's focus, which, from the figure, is evident will be inverted.

Let C repreſent all the rays proceeding from the point B of the object, and E the pencil of rays proceeding from the point A.

The rays C falling parallel upon the great mirror, will be thence reflected, and converge in the direction D G; and by croſſing at I, the principal focus of the mirror, they will form the upper extremity of the inverted image I K, ſimilar to the lower extremity B of the object A B.

In like manner, the rays E, which come from the top of the object, and fall upon the great mirror at F, are thence reflected converging to it's focus, where they form the lower extremity K of the inverted image I K, ſimilar to the upper extremity A of the object A B.

The rays from theſe two pencils paſs on from I and K to the ſmall mirror L, the rays from F falling upon it at h; thoſe from D falling upon it at g, from which points they are again reflected.

2. The focus of the ſmall ſpeculum is at n, a little beyond the place where the image is formed by the great ſpeculum.

If the focus of this mirror fell preciſely on m, where the image from the other is formed, the rays would be reflected parallel therefrom; but as it is ſomewhat beyond or longer than that diſtance, they are reflected converging in the direction g N.

3. The converging pencil of rays g N, proceeding from the point a, and reflected by the ſmall mirror, would coincide beyond the teleſcope if they were not refracted by the eye-

glaſſes. It is the ſame with the other converging pencil.

But to render the inſtrument ſhorter, theſe converging rays are made to fall on the lens R in the eye-tube, which increaſes their convergence, and makes them coincide at a and b, where they form an erect image of the object at a b. This image being at the focus of the lens S, the rays proceeding from the image formed there, are ſo refracted by it as to emerge parallel to the eye, and thus produce diſtinct viſion.

The light which falls upon the ſurface of the large mirror is reflected to the ſmall mirror; the eye therefore receives from the teleſcope a quantity of light, which is to that which it would receive by naked viſion, nearly in the ſame proportion that the ſurface of the large mirror is to the ſurface of the ſmall hole at e, near the pupil of the eye.

The rays paſſing on from the image, paſs through the ſecond eye-glaſs S, and through a ſmall hole e enter the eye f, which ſees the image a b, and by means of the eye-glaſs under the large angle c e d, the ſecond glaſs increaſes the field, and renders the image more perfect.

In order to ſuit different eyes and diſtances, there is a ſmall rod with a ſcrew at one end; this ſcrew goes through the arm which is fixed to the ſmall reflector, ſo that by turning the end it brings it nearer, or removes it further from the larger ſpeculum.

An eye-ſtop is placed at the laſt image, to cut off the ſuperfluous rays; a very ſmall hole is made at e, to let the rays paſs to the eye.

To ſee near objects, or to accommodate the teleſcope for long-ſighted people, the ſmall mirror muſt be moved further from the large mirror than when uſed for diſtant objects or a common ſight; for if an object comes nearer, i.'s image at m will come nearer n, and as n m grows leſs, n P will grow greater, and will come nearer the lens R; to reduce or bring it back, the mirror muſt be removed further.

For *ſhort-ſighted people*, the focus P muſt be brought nearer R, to make the rays more divergent; that is, n P muſt be longer, and conſequently n m ſhorter, or h g brought nearer to D U, V F.

Therefore for diſtant objects, and ſhort-ſighted people, *turn the ſcrew to the right;* but for near objects and old eyes, *turn to the left.*

This teleſcope, as you have ſeen, ſhews the object erect, but not ſo bright as in refracting teleſcopes; becauſe glaſs tranſmits more light than metal reflects. It has been eſtimated, that one third of the light received is loſt by reflection.

The *viſible area* of an object is as the breadth of the eye-glaſs; for if the image at I K, and the eye-glaſs be increaſed, the image at m will alſo be increaſed, becauſe the angles of incidence and reflection at h g are equal, and conſequently the viſible part of the object is increaſed.

The brightneſs of the object is in proportion to the aperture, for the larger this is, the greater is the quantity of light that comes to the eye.

The extreme parts of the image are leſs bright than the reſt, becauſe the ſhadow of the ſmall ſpeculum falls on the outſide, but towards the middle it only covers the hole.

To render the determination of the magnifying power more eaſy, I ſhall conſider the tube to be twelve inches long, two inches diameter; the concave ſpeculum, at the bottom of the tube, to be of ſeven inches focus, and two inches diameter;

the hole in the center $\frac{6}{12}$ of an inch in diameter; the focus of the ſmall mirror $\frac{18}{12}$, it's diameter $\frac{8}{12}$ of an inch; the firſt eye-glaſs about three inches focus, the ſecond about $\frac{10}{12}$. We muſt now refer back to our former inſtructions on the principles of rays of light, when reflected from a ſpherical concave mirror.

You will recollect, 1ſt, That the light, which comes from a very diſtant object, is ſo reflected that the point where they meet, and where the image is formed, is ¼ part of the diameter of the ſphere, of which the great ſpeculum is a ſegment. 2d, That if the object is at the focus of a concave ſpherical mirror, the rays falling therefrom are reflected parallel to each other.

Now diſtant objects ſeen through the reflecting teleſcope, form an inverted image at I K, the focal point of the large ſpeculum, and nine inches therefrom, and the image and object both appear under the ſame angle from the vertex of the mirror; this image at the focus I K being the baſe of two angles, whoſe ſummits are the centers of the two ſpherical mirrors. Now the diſtance of the focus of the two mirrors is as 1½ to 9, or as 3 to 18, by taking away the fraction; or as 1 to 6, by dividing the terms by 3: therefore the two angles are in the proportion of 1 to 6, that is, the angle ſubtended by the ſpherical ſurface, of which A B is a portion, is ſix times larger than what the object ſubtends at the ſurface of the larger mirror; conſequently if the eye was placed in the parallel rays proceeding from the ſmall ſpeculum, it would ſee the object perfectly therein, and magnified in the proportion of the focal diſtances of the two metals, that is, as 6 to 1.

Now the two lenſes in the eye-tube form a teleſcope, whoſe property, on the principles already

ready laid down, is to magnify the object in the proportion that the focus of the lens S exceeds that of R, in this inſtance, as 36 to 10; but the teleſcope was before ſhewn to magnify in the proportion of 6 to 1. By combining theſe proportions, we ſhall obtain 10 × 1, and 36 × 6, or 10 to 216, or nearly as 1 to 22.

OF THE NEWTONIAN TELESCOPE.

The teleſcope of *Newton* differs a little in the conſtruction from that of *Gregory*, but it is founded upon the ſame principles, as well geometrical as phyſical.

It conſiſts, like the former, of a tube to receive the metals; the upper end of the tube is open; at the bottom of this is placed *a concave metal reflector*, and *a plain ſmall metal reflector*, inclined 45 degrees to the axis of the large reflector. This ſmall reflector muſt be of an oval form; the length of the oval ſhould be to the breadth as 2 to 1, on account of the obliquity of it's poſition; it is ſupported on an arm fixed to the ſide of the tube; an eye-glaſs is placed in a ſmall tube, moveable in the larger tube, ſo as to be perpendicular to the axis of the large reflector, the perpendicular line paſſing through the center of the ſmall mirror. The ſmall mirror is to be ſituated between the large mirror and it's focus, that it's diſtance from this focal point may be equal to the diſtance from the center of the mirror to the focus of the eye-glaſs.

The tube v x z y, *fig.* 3, *pl.* 8, being turned with it's open end towards the object, parallel rays coming therefrom will be reflected by the concave mirror to it's focus, where it would form an inverted image of the object, but from the interpoſition of the ſmall reflector f e g, they are prevented coming to the focus, and are reflected to t, the focus of the eye-glaſs, where they form an image equal to what would have been formed at the focus of the concave mirror. This image being in the focus of the eye-glaſs, the rays proceeding therefrom will be ſo refracted by the lens, as to emerge parallel to the eye, and therefore properly conſtituted to produce diſtinct viſion.

If the face be turned towards the open end of the tube, and the eye be applied at h, the object will appear inverted; but if the face be turned towards c d, the object will be erect; the latter poſition is in moſt caſes very inconvenient.

The magnifying power is in the ſame proportion as the focal diſtance of the concave ſpeculum exceeds that of the eye-glaſs. This teleſcope will bear a greater aperture than the Gregorian reflector; leſs light is alſo loſt from the oval plane, than from a ſpherical reflector. It is by means of a Newtonian teleſcope that Dr. Herſchel has added ſo many valuable diſcoveries to aſtronomy.

There is another kind of reflecting teleſcope, known by the name of Caſſegrain; but as it is not uſed at preſent, it will be needleſs for me to deſcribe it here; I ſhall therefore only obſerve, that it is ſimilar to the Gregorian teleſcope, except in one inſtance, namely, that the ſmall ſpeculum is convex inſtead of concave.

The diſadvantages under which reflecting teleſcopes labour, ariſe from their requiring larger apertures to tranſmit the ſame quantity of light; from being more affected by the imperfections of the atmoſphere than a refracting teleſcope; from being liable to tarniſh; but principally from the imperfections of the workmanſhip of the object-ſpeculum,

culum, which injures them more than equal faults in the object-glaſs of refractors.

In the hands of a man whoſe mind is well directed, every part of ſcience is made uſeful; among many inſtances of this, I ſhall give you one from the learned Mr. Jacob Bryant's treatiſe on the Authenticity of the Scriptures, in which, from the teleſcopes we have been conſidering, he ſhews the weakneſs of ſome infidel objections to revelation. Thus he ſhews, that there is no more reaſon to object to the authenticity of the ſcriptures on account of ſome difficulties, than to natural religion or natural philoſophy on the ſame account; for they are equally attended with difficulties. Natural philoſophy abounds with phenomena which we ſee and know, but cannot explain, as gravity, magnetiſm, &c.

If any perſon had prophetically informed *Archimedes* or *Eudoxus*, that viſion would one day be wonderfully aſſiſted by art, and that the manner of improving ſight would be to place a *dark opake ſubſtance* directly between the object and the eye, they muſt have thought the prophet out of his ſenſes. And when they heard that the other method was, in viewing an object, *not to look at it*, but to keep the eye in a quite different direction, how could they digeſt theſe doctrines, by which they were taught, that ſight would be helped by impediments, and that the beſt way of ſeeing objects was looking another way?

Yet whoever is acquainted with the *Gregorian teleſcope*, muſt know, that ſuch a *dark body* does intervene between the eye and the object; and that in the *Newtonian teleſcope* the ſight is directed ſideways, at an angle of 90 degrees. When once known, the thing is found to be conſonant to reaſon and experience.

If then we meet with many things in common life and worldly ſcience, which ſeem difficult to comprehend, and ſome beyond our reaſon, we muſt expect to find others beyond our reaſon in that grand ſyſtem of life and immortality laid before us in holy writ.

LECTURE XXIII.

OF MICROSCOPES.

*BY a microſcope we underſtand *an inſtrument for viewing ſmall objects*, rendering thoſe viſible which would be otherwiſe imperceptible. Microſcopes are divided into three different kinds, *ſingle*, *compound*, and *ſolar*; *ſingle* microſcopes are thoſe which conſiſt of one lens; *compound*, thoſe which are formed of two or more lenſes; *ſolar*, thoſe which are uſed in a dark room, the object being illuminated by the ſun, and the image received on a ſcreen.

It is generally ſuppoſed, that microſcopes were invented about the year 1680, a period fruitful in diſcoveries, when the mind began to emancipate itſelf from thoſe errors and prejudices by which it had been too long enſlaved, to aſſert it's rights, extend it's powers, and follow the paths which lead to truth. The honour of the invention is claimed by the Italians and the Dutch; the name of the inventor, however, is loſt; probably the diſcovery did not at firſt appear ſufficiently important, to engage the attention of thoſe men, who, by their reputation in ſcience, were able to eſtabliſh an opinion of it's merit with the reſt of the world, and hand down the name of the inventor to ſucceeding ages. Men of great literary abilities are apt to deſpiſe the firſt dawnings of invention, not conſidering that all real knowledge is progreſſive, and that what they deem trifling may be the firſt and neceſſary link to a new branch of ſcience.

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* See my Eſſays on the Microſcope, of which I mean to publiſh a new edition the ſame ſize with this work, to which it will be a proper ſupplement, manifeſting the wiſdom of God in the minute parts of creation.

The microſcope extends the boundaries of the organs of viſion; enables us to examine the ſtructure of plants and animals; preſents to the eye myriads of beings, of whoſe exiſtence we had before formed no idea; opens to the curious an exhauſtleſs ſource of information and pleaſure; and furniſhes the philoſopher with an unlimited field of inveſtigation. It leads, to uſe the words of an ingenious writer, to the diſcovery of a thouſand wonders in the works of his hand, who created ourſelves, as well as the objects of our admiration; it improves the faculties, exalts the comprehenſion, and multiplies the inlets to happineſs; is a new ſource of praiſe to him, to whom all we pay is nothing of what we owe; and while it pleaſes the imagination with the unbounded treaſures it offers to the view, it tends to make the whole life one continued act of admiration. For there is no object ſo inconſiderable, that it has not ſomething to invite the curious eye to examine it; nor is there any, which, when properly examined, will not amply repay the trouble of inveſtigation.

It is not difficult to fix the period when the microſcope firſt began to be generally known, and was uſed for the purpoſe of examining minute objects; for though we are ignorant of the name of the firſt inventor, we are acquainted with the names of thoſe who firſt engaged the public attention, by exhibiting ſome of it's wonderful effects. Zacharias Janſens and his ſon had made microſcopes before the year 1619, for in that year the ingenious Cornelius Drebell brought one, which was made by them, with him into England, and ſhewed it to William Borrell and others. It is poſſible this inſtrument of Drebell's was not ſtrictly what is now meant by a microſcope, but was rather a kind of microſcopic teleſcope, ſomething ſimilar in principle to that lately deſcribed by Mr. Aepinus, in a letter to the Academy of Sciences at Peterſburg. It was formed of a copper tube ſix feet long and one inch diameter, ſupported by three braſs pillars in the ſhape of dolphins; theſe were fixed to a baſe of ebony, on which the objects to be viewed by the microſcope were alſo placed. In contradiction to this, Fontana, in a work which he publiſhed in 1646, ſays, that he had made microſcopes in the year 1618: this may be alſo very true, without derogating from the merit of the Janſens, for we have many inſtances in our own times of more than one perſon having executed the ſame contrivance, nearly at the ſame time, without any communication from one to the other. In 1685, Stelluti publiſhed a deſcription of the parts of a bee, which he had examined with a microſcope.

If we conſider the microſcope as an inſtrument conſiſting of one lens only, it is not at all improbable, that it was known to the ancients much ſooner than the laſt century, nay, even in a degree to the Greeks and Romans; for it is certain, that ſpectacles were in uſe long before the above-mentioned period. Now as the glaſſes of theſe were made of different convexities, and conſequently of different magnifying powers, it is natural to ſuppoſe, that ſmaller and more convex lenſes were made, and applied to the examination of minute objects. In this ſenſe, there is alſo ſome ground for thinking the ancients were not ignorant of the uſe of lenſes, or at leaſt of what approached nearly to, and might in ſome inſtances be ſubſtituted for them.

OF THE OPTICAL EFFECT OF MICROSCOPES.

It has been already obſerved, that the human eye is ſo conſtituted, that we cannot ſee an object diſtinctly when it is nearer the eye than ſix inches. To enable us to ſee objects nearer is the deſign of microſcopes, for by this means we are enabled to diſcern thoſe objects which, from their minuteneſs, become imperceptible at a ſmall diſtance. Hence a microſcope is ſaid to magnify the objects ſeen through it; but this expreſſion is only true with reſpect to the *apparent* magnitude of the object.

To have right ideas on this ſubject, you muſt diſtinguiſh the apparent from the real magnitude of objects; the real magnitude of an object is the object of geometry, and remains *invariable* as long as the object continues in the ſame ſtate; the apparent magnitude may be *infinitely varied*, while the real ſize remains unaltered. Thus the ſtars in the heavens appear to us exceeding ſmall, although their real ſize is prodigious; this difference is occaſioned by their immenſe diſtance. If we could approach them, we ſhould find them increaſe in ſize as the diſtance diminiſhes; the apparent magnitude depending in a great degree on the angle under which it is ſeen, and this angle increaſes or diminiſhes, according as the object is nearer to or further from the eye.

Thus let P O Q, *fig.* 4, *pl.* 8, be the object of our ſight; this, if the eye be at A, will appear under the angle P A Q, called the *viſual* angle, and which determines in a great meaſure the apparent ſize of an object. It is plain from hence, that the further the eye is from the object, the ſmaller is this angle; and that thus the largeſt bodies may be ſeen under an exceeding ſmall angle, if they are at a ſufficient diſtance.

If the eye be at B, the object will be ſeen under the angle O B Q, which is viſibly larger than the angle P A Q. Let the eye be at c, the angle P C Q is larger than P B Q; and ſo on, the nearer the eye is to the object, the larger is the viſual angle.

From hence it follows, that the apparent diameter of an object ſeen by the naked eye, may be magnified in any proportion we pleaſe; for as the apparent diameter is increaſed in proportion as the diſtance from the eye is leſſened, we have only to leſſen the diſtance of the object from the eye, in order to increaſe the apparent diameter thereof.* Thus, ſuppoſe there is an object, A B, *pl.* 8, *fig.* 5, which to an eye at E ſubtends or appears under the angle A E B, we may magnify the apparent diameter in what proportion we pleaſe, by bringing our eye nearer to it. If, for inſtance, we would magnify it in the proportion of F G to A B; that is, if we would ſee the object under an angle as large as F E G, or would make it appear the ſame length that an object as long as F G would appear, it may be done by coming nearer to the object. For the apparent diameter is as the diſtance inverſely; therefore, if C D is as much leſs than C E, as F G is greater than A B, by bringing the eye nearer to the object in the proportion of C D to E D, the apparent diameter will be magnified in the proportion of F G to A B; ſo that the object A B, to the eye at D, will appear as long as an object F G would appear to the eye at E. In the ſame manner, we might ſhew, that the apparent diameter of an object, when ſeen by the naked eye, may be infinite. For ſince the apparent diameter is reciprocally as the diſtance of the eye, when the diſtance of the eye is nothing, or when the eye is cloſe to the object at C, the apparent diameter will be the reciprocal of nothing, or infinite.

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* Rutherforth's Syſtem of Natural Philoſophy, p. 330.

There is, however, one great inconvenience in thus magnifying an object, without the help of glaſſes, by placing the eye nearer to it. The inconvenience is, that we cannot ſee an object diſtinctly, unleſs the eye is about five or ſix inches from it; therefore, if we bring it nearer to our eye than five or ſix inches, however it may be magnified, it will be ſeen confuſedly. Upon this account, the greateſt apparent magnitude of an object that we are uſed to, is the apparent magnitude when the eye is about five or ſix inches from it: and we never place an object much within that diſtance; becauſe, though it might be magnified by this means, yet the confuſion would prevent our deriving any advantage from ſeeing it ſo large. The ſize of an object ſeems extraordinary, when viewed through a convex lens; not becauſe it is impoſſible to make it appear of the ſame ſize to the naked eye, but becauſe at the diſtance from the eye which would be neceſſary for this purpoſe, it would appear exceedingly confuſed; for which reaſon, we never bring our eye ſo near to it, and conſequently as we have not been accuſtomed to ſee the object of this ſize, it appears an extraordinary one.

On account of the extreme minuteneſs of the atoms of light, it is clear, a ſingle ray, or even a ſmall number of rays, cannot make a ſenſible impreſſion on the organ of ſight, whoſe fibres are very groſs, when compared to theſe atoms; it is neceſſary, therefore, that a great number ſhould proceed from the ſurface of an object, to render it viſible. But as the rays of light, which proceed from an object, are continually diverging, different methods have been contrived, as we have already ſhewn you, either of uniting them in a given point; or of ſeparating them at pleaſure.

Thus, by the help of convex lenſes, we unite in the ſame ſenſible point a great number of rays, proceeding from one point of an object; and as each ray carries with it the image of the point from whence it proceeded, all the rays united muſt form an image of the object from whence they were emitted. This image is brighter, in proportion as there are more rays united; and more diſtinct, in proportion as the order in which they proceeded, is better preſerved in their union.

We perceive the preſence and figure of objects by the impreſſion each reſpective image makes on the retina; the mind, in conſequence of theſe impreſſions, forms concluſions concerning the ſize, poſition, and motion of the object. It muſt however be obſerved, that theſe concluſions are often rectified or changed by the mind, in conſequence of the effects of more habitual impreſſions. For example; there is a certain diſtance, at which, in the general buſineſs of life, we are accuſtomed to ſee objects: now, though the meaſure of the image of theſe objects changes conſiderably when they move from, or approach nearer to us, yet we do not perceive that their ſize is much altered: but beyond this diſtance, we find the objects appear to be diminiſhed, or increaſed, in proportion as they are more or leſs diſtant from us.

For inſtance, if I place my eye ſucceſſively at two, at four, and at ſix feet from the ſame perſon, the dimenſions of the image on the retina will be nearly in the proportion of 1, of $\frac{1}{2}$, of $\frac{1}{3}$, and conſequently they ſhould appear to be diminiſhed in the ſame proportion; but we do not perceive this diminution, becauſe the mind has rectified the impreſſion received on the retina. To prove this, we need only conſider, that if we ſee a perſon at 120 feet diſtance, he will not appear ſo ſtrikingly ſmall, as if the ſame perſon ſhould be viewed from the top of a tower, or other building, 120 feet high, a ſituation to which we had not been accuſtomed.

From hence, alſo, it is clear, that when we place a glaſs between the object and the eye, which from it's figure changes the direction of the rays of light from the object, this object ought not to be judged as if it were placed at the ordinary reach of the ſight, in which caſe we judge of it's ſize more by habit than by the dimenſions of the images formed on the retina: but it muſt be eſtimated by the ſize of the image in the eye, or by the angle formed at the eye, by the two rays which come from the extremity of the object.

If the image of an object, formed after refraction, is greater or leſs than the angle formed at the eye, by the rays proceeding from the extremities of the object itſelf, the object will appear alſo proportionably enlarged or diminiſhed; ſo that if the eye approaches to, or removes from, the laſt image, the object will appear to increaſe or diminiſh, though the eye ſhould in reality remove from it in one caſe, or approach towards it in the other; becauſe the image takes place of the object, and is conſidered inſtead of it.

The apparent diſtance of an object from the eye, is not meaſured by the real diſtance from the laſt image; for, as the apparent diſtance is eſtimated principally by the ideas we have of their ſize, it follows, that when we ſee objects, whoſe images are increaſed or diminiſhed by refraction, we naturally judge them to be nearer or further from the eye, in proportion to the ſize thereof, when compared to that with which we are acquainted. The apparent diſtance of an object is conſiderably affected by the brightneſs, diſtinctneſs, and magnitude thereof. Now as theſe circumſtances are, in a certain degree, altered by the refraction of the rays in their paſſing through different media, they will alſo, in ſome meaſure, affect the eſtimation of the apparent diſtance.

OF THE SINGLE MICROSCOPE.

The ſingle microſcope renders minute objects viſible, by means of a ſmall glaſs globule, or convex lens, of a ſhort focus. Let E Y, *fig.* 6, *pl.* 8, repreſent the eye; and O B, a ſmall object ſituated very near to it, conſequently the angle of it's apparent magnitude very large. Let the convex lens R S be interpoſed between the eye and the object, ſo that the diſtance between it and the object may be equal to the focal length; and the rays which diverge from the object, and paſs through the lens, will afterwards proceed, and conſequently enter the eye parallel: after which, they will be converged, and form an inverted image on the retina, and the object will be clearly ſeen; though, if removed to the diſtance of ſix inches, it's ſmallneſs would render it inviſible.

When the lens is not held cloſe to the eye, the object is ſomewhat more magnified; becauſe the pencils, which paſs at a diſtance from the center of the lens, are refracted inward towards the axis, and conſequently ſeem to come from points more remote from the center of the object.

Fig. 10, *pl.* 8, may, perhaps, give the reader a ſtill clearer view, why a convex lens increaſes the angle of viſion. Without a lens, as F G, the eye at A would ſee the dart B C under the angle b A c; but the rays B F and C G from the extremities of the dart in paſſing through the lens, are refracted to the eye in the directions f A and G a, which cauſes the dart to be ſeen under the much larger angle D A E (the ſame as the angle f A g). And therefore, the dart B C will appear ſo much magnified, as to extend in length from D to E.

The object, when thus ſeen diſtinctly, by means of the ſmall lens, appears to be magnified nearly in the proportion which the focal diſtance of the glaſs bears to the diſtance of the objects, when viewed by the naked eye..

To explain this further, place the eye cloſe to the glaſs, that as much of the object may be ſeen at one view as is poſſible; then remove the object to and fro, till it appears perfectly diſtinct, and well defined; now remove the lens, and ſubſtitute in it's place a thin plate, with a very ſmall hole in it, and the object will appear as diſtinct, and as much magnified, as with the lens, though not quite ſo bright; and it appears as much more magnified in this caſe, than it does when viewed with the naked eye, as the diſtance of the object from the hole, or lens, is leſs than the diſtance at which it may be ſeen diſtinctly with the naked eye.

From hence we ſee, that the whole effect of the lens or microſcope is to render the object diſtinct, which it does by aſſiſting the eye to increaſe the refraction of the rays in each pencil; and that the apparent magnitude is entirely owing to the object being ſeen ſo much nearer the eye than it could be viewed without it.

In other words, a ſingle microſcope removes the confuſion that accompanies objects when ſeen very near the eye, while it leaves the viſual angle the ſame. 1. It removes the confuſion, for the object being placed in the focus of the lens, the rays emerging from thence are parallel, which you know is neceſſary to diſtinct viſion. 2. The angle is the ſame, for whether the eye touches the glaſs, or is removed a little way from it, it appears under the ſame angle as it would to the eye placed where the glaſs is fixed.

Single microſcopes magnify the diameter of the object, as we have already ſhewn, in the proportion of the focal diſtance (to the limits of diſtinct viſion with the naked eye) to eight inches. For example, if the ſemi-diameter of a lens, equally convex on both ſides, be half an inch, which is alſo equal to it's focal diſtance, we ſhall have as $\frac{1}{2}$ is to 8, ſo is 1 to 16; that is, the diameter of the object in the proportion of ſixteen to one. As the diſtance of eight inches is always the ſame, it follows, that by how much the focal diſtance is ſmaller, there will be a greater difference between it and the eight inches; and conſequently, the diameter of the object will be ſo much the more magnified, in proportion as the lenſes are ſegments of ſmaller ſpheres.

As the cloſer the object is to the eye the larger it appears, it follows, that a double and equally convex lens is preferable to a plano-convex lens, becauſe with equal convexities the focal length of the former is only half as long as the latter. Now as the double convex conſiſts of two ſegments of a ſphere, the more an object is to be magnified, the greater muſt be the convexity, and therefore the ſmaller the ſphere, till at laſt the utmoſt degree of magnifying power will require that theſe ſegments become hemiſpheres, and conſequently the lens will be reduced to a perfect ſpherule, or very ſmall ſphere.

Very extraordinary magnifying powers may be obtained by means of ſmall ſpherules, for the focus of parallel rays is only half the radius diſtant from the ſpherule; therefore, if the radius of the ſpherule be $\frac{1}{10}$ of an inch, the eye will have diſtinct viſion of an object by means thereof at the diſtance of a radius and a half, i. e. $\frac{3}{20}$ of an inch, which is but the fortieth part of 6 inches, ſo that the length of an object will be magnified 40 times, the ſurface 1600.

Of the Double or Compound Microscope.

In the compound microſcope, the image is viewed inſtead of the object, which image is magnified by a ſingle lens, as the object is in a ſingle microſcope. It conſiſts of an object lens, L N, *fig.* 8, *pl.* 8, and an eye-glaſs F G. The object O B is placed a little further from the lens than it's principal focal diſtance, ſo that the pencils of rays proceeding from the different points of the object through the lens, may converge to their reſpective foci, and form an inverted image of the object at P Q; which image is viewed by the eye through the eye-glaſs F G, which is ſo placed, that the image may be in it's focus on one ſide, and the eye at the ſame diſtance on the other. The rays of each pencil will be parallel, after paſſing out of the glaſs, till they reach the eye at E, where they will begin to converge by the refractive powers of the humours; and after having croſſed each other in the pupil, and paſſed through the cryſtalline and vitreous humours, they will be collected in points on the retina, and form a large inverted image thereon.

It will be eaſy, from what has been already explained, to underſtand the reaſon of the magnifying power of a compound microſcope. The object is magnified upon two accounts; firſt, becauſe if we viewed the image with the naked eye, it would appear as much larger than the object, as the image is really larger than it, or as the diſtance f R is greater than the diſtance f b; and ſecondly, becauſe this picture is again magnified by the eye-glaſs, upon the principle explained in the foregoing article on viſion by ſingle microſcopes.

But it is to be noted, that the image formed in the focus of a lens, as is the caſe in the compound microſcope, differs from the real object in a very eſſential particular; that is to ſay, the light being emitted from the object in every direction, renders it viſible to an eye placed in any poſition; but the points of the image formed by a lens, emitting no more than a ſmall conical body of rays, which arrives from the glaſs, can be viſible only when the eye is ſituated within it's confine. Thus the pencil, which emanates from O in the object, and is converged by the lens to D, proceeds afterwards diverging towards H, and therefore never arrives at the lens F G, nor enters the eye at E. But the pencils which proceed from the points o and b, will be received on the lens F G, and by it carried parallel to the eye; conſequently, the correſpondent points of the image Q P will be viſible; and thoſe which are ſituated farther out towards H and I, will not be ſeen. This quantity of the image Q P, or viſible area, is called the field of view.

Hence it appears, that if the image be large, a very ſmall part of it will be viſible; becauſe the pencils of rays will for the moſt part fall without the eye-glaſs F G. And it is likewiſe plain, that a remedy which would cauſe the pencils, which proceed from the extremes O and B of the object, to arrive at the eye, will render a greater part of it viſible; or, in other words, enlarge the field of view. This is effected by the interpoſition of a broad lens D E of a proper curvature, at a ſmall diſtance from the focal image. For, by that means, the pencil DM, which would otherwiſe have proceeded towards H, is refracted to the eye as delineated in the figure, and the mind conceives from thence the exiſtence of a radiant point at Q, from which the rays laſt proceeded. In like manner, and by a parity of reaſon, the other extreme of the image is ſeen at P, and the intermediate points are alſo rendered viſible. On theſe conſiderations it is, that compound microſcopes are uſually made to conſiſt of an object lens LN, by which the image is formed, enlarged, and inverted; an amplifying lens DE, by which the field of view is enlarged, and an eye-glaſs or lens, by means of which the eye is allowed to approach very near, and conſequently to view the image under a very great angle of apparent magnitude. It is now cuſtomary to combine two or more lenſes together at the eye-glaſs, in the manner of Euſtachio Divini and M. Joblot; by which means, the aberration of light from the figure is in ſome meaſure corrected, and the apparent field increaſed.

Of the Solar Microscope.

In this inſtrument, the image of the object is thrown upon a ſcreen in a darkened room. It may be conſidered under two diſtinct heads: 1ſt, the mirror and lens, which are intended to reflect the light of the ſun upon the object; and 2dly, that part which conſtitutes the microſcope, or which produces the magnified image of the object, *fig.* 9, *pl.* 8. Let NO repreſent the ſide of a darkened chamber; GH a ſmall convex lens, fixed oppoſite to a perforation in the ſide NO; AB a plane mirror, or looking-glaſs, placed without the room to reflect the ſolar rays a, b, c, &c. on the lens CD, by which they are converged and concentrated on the object fixed at E F.

2. The object being thus illuminated, the ray which proceeds from E will be converged by the lens G H to a focus K, on the ſcreen L M; and the ray which comes from F will be converged to I, and the intermediate points will be delineated between I and K; thus forming a picture, which will be as much larger than the object, in proportion as the diſtance of the ſcreen exceeds that of the image from the object.

GENERAL OBSERVATIONS.

From what has been ſaid, it appears plainly, the advantages we gain by microſcopes are derived, firſt, from their magnifying power, by which the eye is enabled to view more diſtinctly the parts of minute objects: ſecondly, that by their aſſiſtance, more light is thrown into the pupil of the eye, than is done without them. The advantages procured by the magnifying power, would be exceedingly circumſcribed, if they were not accompanied by the latter: for if the ſame quantity of light is diffuſed over a much larger ſurface, it's force is proportionably diminiſhed; and therefore the object, though magnified, will be dark and obſcure. Thus, ſuppoſe the diameter of the object to be enlarged ten times, and conſequently the ſurface one hundred times, yet, if the focal diſtance of the glaſs was eight inches, (provided this was poſſible) and it's diameter only about the ſize of the pupil of the eye, the object would appear one hundred times more obſcure when viewed through the glaſs, than when it was ſeen by the naked eye; and this even on the ſuppoſition, that the glaſs tranſmitted all the light which fell upon it, which no glaſs can

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do. But if the glaſs was only four inches focal diſtance, and it's diameter remained as before, the inconvenience would be vaſtly diminiſhed; becauſe the glaſs could be placed twice as near the object as before, and would conſequently receive four times as many rays as in the former caſe, and we ſhould therefore ſee it much brighter than before. By going on thus, diminiſhing the focal diſtance of the glaſs, and keeping it's diameter as large as poſſible, we ſhall perceive the object proportionably magnified, and yet remain bright and diſtinct. Though this is the caſe in theory, yet there is a limit in optical inſtruments, which is ſoon arrived at, but which cannot be paſſed. This ariſes from the following circumſtances.*

1. The quantity of light loſt in paſſing through the glaſs.

2. The diminution in the diameter of the glaſs or lens itſelf, by which it receives only a ſmall quantity of rays.

3. The extreme ſhortneſs of the focal diſtance of great magnifiers, whereby the free acceſs of the light to the object we wiſh to view is impeded, and conſequently the reflection of the light from it is weakened.

4. The aberration of the rays, occaſioned by their different refrangibility.

To make this more clear, let us ſuppoſe a lens made of ſuch dull kind of glaſs, that it tranſmits only one half the light that falls upon it. It is evident, that ſuppoſing this lens to be of four inches focus, and to magnify the diameter of the object twice, and it's own breadth equal to that of the pupil of the eye, the object will be four times magnified in ſurface, but only half as bright as if it was ſeen by the naked eye at the uſual diſtance;

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* *Encyclopedia Britannica*, vol. viii. p. 5635.

for the light which falls upon the eye from the object at eight inches diſtance, and likewiſe the ſurface of the object in it's natural ſize, being both repreſented by 1, the ſurface of the magnified object will be 4, and the light which makes it viſible only 2; becauſe though the glaſs receives four times as much light as the naked eye does at the uſual diſtance of diſtinct viſion, yet one half is loſt in paſſing through the glaſs. The inconvenience, in this reſpect, can only be removed ſo far as it is poſſible to increaſe the tranſparency of the glaſs, that it may tranſmit nearly all the rays which fall upon it; and how far this can be done, has not been yet aſcertained.

The ſecond obſtacle to the perfection of microſcopic glaſſes, is the ſmall ſize of great magnifiers; by which means, notwithſtanding their near approach to the object, they receive a ſmaller quantity of light than might be expected. Thus, ſuppoſe a glaſs of only one-tenth of an inch focal diſtance, ſuch a glaſs would increaſe the viſible diameter eighty times, and the ſurface 6400 times. If the breadth of the glaſs could at the ſame time be preſerved as great as the pupil of the eye, which we ſhall ſuppoſe one-tenth of an inch, the object would appear magnified 6400 times, and every part would be as bright as it appears to the naked eye. But if we ſuppoſe the lens to be only $\frac{1}{20}$ of an inch diameter, it will then only receive $\frac{1}{4}$ of the light which would otherwiſe have fallen upon it; therefore, inſtead of communicating to the magnified object a quantity of light equal to 6400, it would communicate an illumination ſuited only to 1600, and the magnified object would appear four times as dim as it does to the naked eye. This inconvenience can, however, be in a great degree removed, by throwing a much larger quantity of light on the object.

The third obſtacle ariſes from the ſhortneſs of the focal diſtance in large magnifiers; this inconvenience can, like the former, be remedied in ſome degree by artificial means of accumulating light; but ſtill the eye is ſo ſtrained, as it muſt be brought nearer the glaſs than it can well bear, which in ſome meaſure ſuperſedes the uſe of very deep lenſes, or ſuch as are capable of magnifying beyond a certain degree.

The fourth obſtacle ariſes from the different refrangibility of the rays of light, and which frequently cauſes ſuch deviations from truth in the appearance of things, that many have imagined themſelves to have made ſurprizing diſcoveries, and have communicated them as ſuch to the world; when, in fact, they have been only optical deceptions, owing to the unequal refraction of the rays.

CONCLUSION.

After all that has been ſaid on optics, &c. the queſtion ſtill occurs, *What is light? how is it formed? and of what ſubſtance?* Theſe are queſtions that have been canvaſſed and diſputed ſince the firſt origin of ſcience and philoſophy; and numberleſs are the conjectures which at different periods have ariſen concerning them in the ſchools of learning.

Empedocles, one of the earlieſt philoſophers of Greece, taught that light was an emanation of certain luminous atoms, ſubtil enough to pervade the inviſible pores of air, water, and other diaphanous bodies. Plato ſeems to have been, in every material circumſtance, of the ſame opinion;

and further maintained, that colour is no more than an extremely rare and ſubtil flame, capable of penetrating the denſeſt bodies. Empedocles accounted for viſion in a two-fold way, that it was performed by the effluvia which proceed from the object, and by the emiſſion of light from the eye, as from a lanthorn. The latter opinion is proved, by a paſſage cited by Ariſtotle; it is a beautiful remains of antiquity. I ſhall give it you from Sydenham's tranſlation:

As when the trav'ller in dark winter's night,
Intent on journey, kindles up a light,
The moon, like ſplendor of an oil-fed flame,
He ſets it in ſome lantern's horny frame;
Calm and ſerene there ſits the tender form,
Screen'd from rough winds, and from the wintry ſtorm.
In vain rude airs aſſault the gentle fire,
Their forces break, diſperſe, and they retire;
Fences ſecure, tho' thin, the fair incloſe,
And her bright head ſhe lifts amidſt her foes.
Thro' the ſtrait pores of the tranſparent horn,
She ſhoots her radiance, mild as early morn.
Forth fly the rays; their ſhining path extends,
Till loſt in the wide air, their leſs'ning luſtre ends.
So when the fire freſh lighted from on high,
Sits in the circling pupil of an eye;
O'er it, tranſparent veils of fabric fine
Spread the thin membrane, and defend the ſhrine;
The ſubtil flame incloſing like a mound,
Safe from the flood of humours flowing round.
Forth fly the rays, and their bright paths extend,
Till, in the wide air loſt, their luſtres end.*

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* Nor is this reaſoning of the ancients to be altogether deſpiſed, for there are various arguments and experiments to prove that the ſeat of ſenſe is not entirely paſſive in receiving images, but that it alſo directs a ray from itſelf, to every object it perceives. The action and re-action between objects and the ſeat of ſenſe is wholly reciprocal." A. Wilſon, M. D. *Medical Reſearches.*

Deſcartes maintained, that light, as it exiſted in the luminous body, is nothing but a power or faculty of exciting in us a very clear and vivid ſenſation; and that the inviſible pores of lucid bodies are pervaded by a ſubtil and highly elaſtic matter, capable of being impelled by theſe bodies, and of producing on the organs of viſion, when properly formed, the perception of light.

Sir Iſaac Newton ſeems to have formed no direct opinion on the ſubject; from what he has ſaid we may conclude, he thought it conſiſted of ſolid particles of matter, when explaining more particularly the nature of light, he ſays, that it is refracted and reflected by an etherial medium, by the vibrations of which; it communicates heat to bodies, and is put into fits of eaſy reflection and tranſmiſſion.

In the peripatetic ſchool; light was conſidered as a ſubſtance, neither purely ſpiritual nor purely corporeal, and was therefore defined a *materia media*; and indeed, when we contemplate, with a philoſophic eye, the aſtoniſhing effects of light, we find ſufficient ground for accounting it of a nature widely different from lumpiſh, groſs, inactive matter. That light, however, is material, cannot, as we have already ſhewed you, be diſputed with any degree of probability. The materiality not only appears from it's being propagated in time, but from it's not bending into ſhadow. The ſolar rays are not only capable of being collected by a burning-glaſs, but when collected, exhibit marks of a power altogether irreſiſtible. If a diamond, the hardeſt of terreous bodies, be placed in the focus of a burning-glaſs, the light immediately enters it, tears it's parts aſunder, divides and diſſolves them. Here you perceive the lens acting upon the light, and the light upon the diamond. Since, therefore, light both acts and is acted upon, as matter, we muſt allow it's properties to be material.

The unparallelled ſubtilty of light, and the impoſſibility of ſubjecting it to chemical analyſis, render every inquiry into it's eſſence peculiarly arduous and difficult. Many and various are the phenomena which point out the moſt intimate and immediate connection between fire and light. You all know, that thoſe bodies which are heated moſt intenſely, are moſt luminous, and that the light of the ſun concentrated by convex glaſſes, produces a degree of heat almoſt irreſiſtible. Here you perceive, that fire produces light, and light produces the moſt intenſe heat. If, therefore, the ſame cauſes produce the ſame effects, or, inverting the axiom, if the ſame effects proceed from the ſame cauſes, it muſt be inferred in the preſent inſtance, that light and fire are either one and the ſame ſubſtance, or at leaſt in the immediate chain of cauſe and effect.

The connection between fire and light is further evinced by the well-known effects of the latter on moſt bodies; innumerable experiments ſhew, that there is a certain degree of heat at which bodies become luminous, and that all bodies which ſuſtain that heat, without being converted into vapour, may univerſally be ignited. There are even ſome ſubſtances, which, though they evaporate at a degree of heat far below that at which they ſhould begin to ſhine, may, by proper management, be ignited.

It now, I think, appears, that when Plato defined light "a rare and ſubtil flame," he came nearer the truth than later philoſophers have in general imagined. Can you deſire a more convincing proof of the ſolid judgment and penetration of that ancient ſage, than that after the lapſe of ſo many centuries, and the vaſt progreſs made in the ſcience of nature, we are under the neceſſity of rejecting the theories of the moderns, to revive his long exploded doctrine, as moſt conſonant with facts and experiments. For, if to the arguments already uſed to prove the identity of fire and light, it be added, that light and heat diffuſe themſelves from a center outward, that they act in ſtrait lines, and are ſubject to the ſame laws of reflection, we can hardly withhold our aſſent from the Platonic doctrine.

It may be further obſerved, that in general no light is excited until a decompoſition takes place, and the fixed, or latent fire, begins to be ſeparated from the bodies: light may be therefore conſidered as fire paſſing through certain ſtrainers well defined, and as exiſting in a more pure and ſimple ſtate, and being leſs incumbered with terreous gravitating matter, than fire.

And if you ſurvey the various operations of nature, with that attention and accuracy that are neceſſary in the proſecution of phyſical inquiries, I think I may venture to aſſert, that you will not meet with a ſingle inſtance from which it can appear, that light can be excited without the concurrence of the elementary principle of fire.

I have now finiſhed another ſet of Lectures, and have given you an account of the known properties of light, and among many other things have explained to you the wonderful mechaniſm of the eye, whereby it is rendered the means of viſion; and ſhewn you what aſſiſtance it receives from glaſſes. It has here alſo been ſhewn you, that the particles, of which light is compoſed, are of different colours, and that the colour of each particle is laſting and permanent, ſo as not to be changed either by refraction or reflection; and that thoſe particles which differ as to colour, differ alſo as to refrangibility; and that light, by being thus differently coloured, dreſſes nature in various beauties. In theſe Lectures I have explained to you the principles of the microſcope and teleſcope, inſtruments, by which the boundaries of human knowledge have been much enlarged. In this ſet of Lectures there are further proofs, that "*air*, *fire*, and *light*, are the powers in nature by which all natural motion and life are preſerved: the moſt ignorant are ſenſible of this truth, and it cannot be contradicted by the moſt learned."

From the diſcoveries laid before you in theſe Lectures, it is evident, "that the works of creation are infinitely more glorious than they appear to be; that they are ſeen by us under thoſe circumſtances and diſadvantages which obſcure their true character and intrinſic ſplendor; that in proportion as our attention is fixed upon them, their luſtre brightens, their excellencies become more conſpicuous."*

I have occaſionally pointed out to you the application of light as a ſignificant emblem in the ſacred writings, in which the material elements of a viſible world are always uſed to lead you to the knowledge of one that is ſpiritual and inviſible. By due attention to theſe, you will be able to perceive the energies of the *Divine Mind* in all the various forms of outward nature, and acknowledge that GOD alone is the beauty and benefit of all HIS works; that, as they cannot exiſt but IN HIM and BY HIM, ſo HIS impreſſion is upon them, and HIS impregnation through them.

Though the elements have a mixture of natural and phyſical evil, yet *divine order* influences throughout, and is an internal principle of good, which is alone all the beauty and beneficence, the whole glory and graciouſneſs that is in them; nor can they poſſibly exhibit any beauty or amiableneſs but what they derive from GOD. All things animate and inanimate co-operate in diſplaying his wiſdom and power; all unite in the univerſal ſong to the glory and praiſe of their beneficent CREATOR.

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* Gray's Sermons, p. 9.

> "Air uttering tells *his harmony* in ſounds;
> The light reveals the *fountain* of it's rays,
> And like the ſeraph kindles in his praiſe.
> ———All echoing the SUPREME's deſign,
> BEAUTY OF LOVE, and SYMMETRY DIVINE!"

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